The Effects of Anthropometrical, Physiological and Environmental Factors on Surfing Performance

by

Matthew John Barlow

A thesis submitted to Plymouth University

in partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

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Abstract

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The aim of this thesis was to investigate how physiological and environmental factors affect surfing performance. Studies were performed that assessed the effect of anthropometric and physiological characteristics of surfers on rank and ability, the effect of creatine supplementation on surfing performance and the effect of wave size, wave period and the ability of surfers on physiological and performance indices of surfing. Study one investigated the effect of the anthropometric variables on rank and rating of ability. This was measured across a sample of 79 surfers ranging from intermediate to professional surfers. Significant correlations were found for endomorphy (r = -0.366, P <0.01), sum of six skinfolds (r = -0.274, P <0.05), Body fat percentage (r = -0.268, P <0.01) and mesomorphy (r = 0.442, P <0.01). Findings suggest that levels of adiposity and muscularity might influence the potential for progression between intermediate and professional level surfing performance. Study two investigated the effect of physiological variables on the national ranking of 18 elite male junior surfers using assessments of maximal oxygen uptake, lower body explosive power, upper body power, agility, and balance. Partial correlations were used to account for the influence of age within the sample and a significant correlation was found between power output at $\dot{V}O_{2peak}$ (r_p = -0.879, P <0.01). Findings suggest that power output at $\dot{V}O_{2peak}$ is an important factor for achieving competitive success in high performance junior surfers. Study three investigated the effect of short term (20g.day^{-1} for 5 days) creatine supplementation on body composition, repeated upper body anaerobic power and competition performance was assessed in 17 club level surfers. Testing comprised assessment of body mass and total body water using bioelectrical impedance analysis, a repeated upper body Wingate based on time motion analysis of competitive surfing. A two-way repeated measures ANOVA found no significant effects of supplementation on laboratory measures of anaerobic power or competitive performance. The fourth study investigated the effects of changes in wave conditions on physiological response and performance parameters of surfing. This was assessed using 39 surfers who participated in 60 surfing sessions where wave conditions were recorded and performance was measured using GPS. The study found that wave height was significantly related to energy expenditure ($r_p = -0.351$, $P < 0.05$), maximum ride speed ($r_p = 0.866$, $P < 0.01$), the standard deviation of maximum ride speeds ($r_p = 0.654$, $P < 0.01$), mean ride time ($r_p = 0.354$, $P < 0.01$), maximum ride time ($r_p = -0.296$, $P < 0.05$), the standard deviation of the ride times expenditure ($r_p = -0.344$, $P < 0.01$), mean ride distance ($r_p = 0.398$, $P < 0.01$), maximum ride time ($r_p = 0.318$, $P < 0.05$), minimum ride distance ($r_p = 0.268$, $P < 0.05$), standard deviation of the ride distances ($r_p = -0.362$, $P < 0.01$), percentage of total distance riding ($r_p = 0.310$, $P < 0.05$), percentage of time spent waiting ($r_p = -0.272$, $P = 0.05$), percentage of total time spent riding ($r_p = 0.396$, $P < 0.01$), percentage of total time in miscellaneous activities ($r_p = 0.471$, $P < 0.01$), total distance riding ($r_p = 0.310$, $P = 0.05$), total distance per hour ($r_p = 0.427$, $P < 0.01$). Wave period was found to be significantly related to average heart rate as a percentage of maximum ($r_p = 0.490$, $P < 0.01$), the percentage of time spent in the "easy" training zone ($r_p = -0.408$, $P < 0.01$), maximum ride speed ($r_p = 0.371$, $P < 0.01$), mean ride time ($r_p = 0.283$, $P < 0.05$), maximum ride distance ($r_p = 0.279$, $P < 0.05$), and the standard deviation of the ride distances ($r_p = 0.325$, $P < 0.05$). The ability levels of the surfers were found to be significantly related to average heart rate as a percentage of maximum ($r_p = -0.412$, $P < 0.01$), percentage of time in the "steady" zone ($r_p = 0.435$, $P < 0.01$), percentage of time in the "intermittent" zone ($r_p = 0.483$, $P < 0.01$), maximum ride speed ($r_p = 0.454$, $P < 0.01$), mean ride distance ($r_p = 0.392$, $P < 0.05$), standard deviation of the ride distances ($r_p = 0.264$, $P < 0.05$), percentage of the total distance riding($r_p = 0.267$, $P < 0.05$), percentage of time paddling ($r_p = 0.364$, $P < 0.05$), percentage of time in miscellaneous activities ($r_p = -0.299$, $P < 0.05$), total distance riding ($r_p = 0.267$, $P < 0.05$) and average speed ($r_p = 0.428$, $P < 0.01$). This thesis has found that ability in surfing is related to anthropometric and physiological measures, creatine supplementation improves peak anaerobic power but does not significantly improve surfing performance in club level surfers and that wave conditions and the skill levels of surfers are significantly related to the physiological and performance parameters of surfing.

Table of contents

List of Figures

List of Tables

Acknowledgements

This study was undertaken in an attempt to further the scientific understanding of the physiological and performance parameters of surfing. The motivation to complete this investigation was a marriage of my interest in exercise physiology and love of surfing. I would like to thank Plymouth University and the Faculty of Science and Technology for its support over the period of this study. I would like to thank Dave Read of the UK Pro Surf Tour and Barrie Hall formerly of the British Surfing Association for their help in gaining access to professional and British junior team surfers. I would also like to thank all of the surfers who participated in my studies for the purpose of data collection. I would like express my gratitude to all of the friends and colleagues who have supported me during my studies especially Richard Kenyon for his technical support without which little data would have been successfully collected; Dr John O`Hara, Dr Susan Taylor and Dr Mick Wilkinson for their advice over many years and support in times of need. Special thanks go to my supervisory team of Dr Karen Gresty, Dr Malcolm Findlay and Prof Carlton Cooke who have all helped to shape my research and provided varied but much needed input; and Dr Mark Davidson for the feedback and support He has provided in his role of internal examiner.

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Author's declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

Work submitted for this research degree at the Plymouth University has not formed part of any other degree either at Plymouth University or at another establishment

In the process of this thesis the author attended the International Society for the Advancement of Kinanthropometry (ISAK) Level 1 course and the British Association of Sports and Exercise Sciences (BASES) / UK coaching council (UKCC) children's welfare in sport course.

Relevant scientific seminars and conferences were regularly attended at which work was often presented; external institutions were visited for consultation purposes and several papers prepared for publication.

Publications:

Barlow, M.J.*;* Findlay, M.; Gresty, K; and Cooke, C.B (2012) Anthropometric variables and their relationship to performance and ability in male surfers. Epub ahead of print. European Journal of Sports Science.

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Conference: British Association of Sports and Exercise Science / ICSEMIS conference 19th -24th July, Glasgow, UK.

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Conference: The European College of Sports Science (ECSS) 13th Annual congress, Estoril, Portugal, July, 2008

Conference Publication: Barlow, M.J.; Findlay, M.; Gresty, K; and Cooke, C.B. Can physiological indices of fitness predict competitive national rank in high performance junior British surfers? The European College of Sports Science (ECSS) 13th Annual congress, Estoril, Portugal, July, 2008.

Word count of main body of thesis: 45,137

Signed: Matt Barlow

Glossary of surfing terms used in this thesis

Back-hand: Surfer riding with their back to the face of the wave.

Barrel: A breaking wave that is cylindrical in shape, allowing the surfer to ride within the breaking part of the wave.

Beach break: A surfing spot where the waves break over a beach / sand bottom.

Break: An area used for surfing

Catch (a wave): The action of paddling into a wave to ride the wave.

Caught inside: To be on the shoreward side of the area where the waves break, an area of turbulent white water and being unable to easily paddle out beyond the area of breaking waves. Often resulting in a hold-down.

Clean: When the winds are light or off-shore giving the waves a glassy appearance.

Close-out: When the wave breaks across its length in a manner to offer no ride-able face.

Duck-dive: The action of diving through a wave with a surfboard. The surfer sinks the nose of the board and uses their knee / foot to push the board under a breaking wave.

Fetch: The distance a wind blows over the ocean to generate waves.

Fore-hand: Surfer riding facing the face of the wave.

Goofy foot: Surfer who rides with their right foot forward.

Hold-down: Often as a result of the surfer being caught inside, wiping-out or attempting to ride a close-out the surfer is unable to surface due to turbulent water or breaking waves.

Left-hander: A wave that breaks from right to left relative to a surfer who is facing the beach from the line-up.

Line up: The area just beyond the breaking waves where surfers wait for a suitable wave to ride. Usually at a specific point perpendicular to the beach / land.

Off-shore wind: A wind blowing in the direction from land to sea. Often resulting in clean waves.

On-shore wind: A wind blowing in the direction from sea to shore. Often resulting in messy waves.

Peel (s): The wave breaks in an organised manner along its length from left to right or right to left.

Point break: A break where waves break along a point of land or rocks, often resulting in long ride-able waves that break in an organised manner.

Pop-up: The action a surfer uses to move from a prone position to the riding position – "popping up" to their feet.

Press-up: A method of advancing from the shore through breaking or broken waves. The surfer performs a press up manoeuvre holding onto their board, the board submerges and passes through the wave whilst the surfer passes over the surface of the wave.

Pumping: Generating speed when riding a wave through compression and extension of the legs.

Radical: An impressive or unusual manoeuvre.

Reef break: A break where waves break of a reef of coral, stone or rock.

Regular foot: Surfer who rides left foot forward.

Right-hander: A wave that breaks from left to right relative to a surfer who is facing the beach from the line-up.

Soup: The area of turbulent water on the shoreward side of the area where the waves break.

Tube: See **barrel**.

Turtle roll: A method of advancing from the shore through breaking or broken waves. The surfer holds the rails of the surfboard and rolls over so that they are submerged holding the board above them. The wave then passes over the bottom of the board.

Take-off zone: The area that waves break and surfers attempt to catch the waves.

Wave-face: The front of a wave upon which surfers travel.

Wave pocket (pocket): The most powerful part of the wave, just ahead of where the wave is breaking

Chapter 1.0 Introduction

Surfing is an intermittent exercise that comprises bouts of high intensity exercise interspersed with periods of low intensity activity and rest. The action of surfing usually involves the surfboard being paddled out in the prone position until the surfer is behind the area of breaking waves at the “line up” or “take-off zone”. Once in the “line up” the surfer waits until a suitable wave approaches, then with some powerful sprint-type arm strokes the surfer accelerates the board to match the speed of the incoming wave to allow the surfer to “catch” the wave as it pitches and begins to break (see Figure. 1.1). Once the surfer catches the wave, they then stand up and accelerate down the unbroken part of the wave and begin to perform a series of manoeuvres on the wave face until the wave breaks completely, the surfer falls or the wave flattens out. This process is then repeated (Lowden 1983).

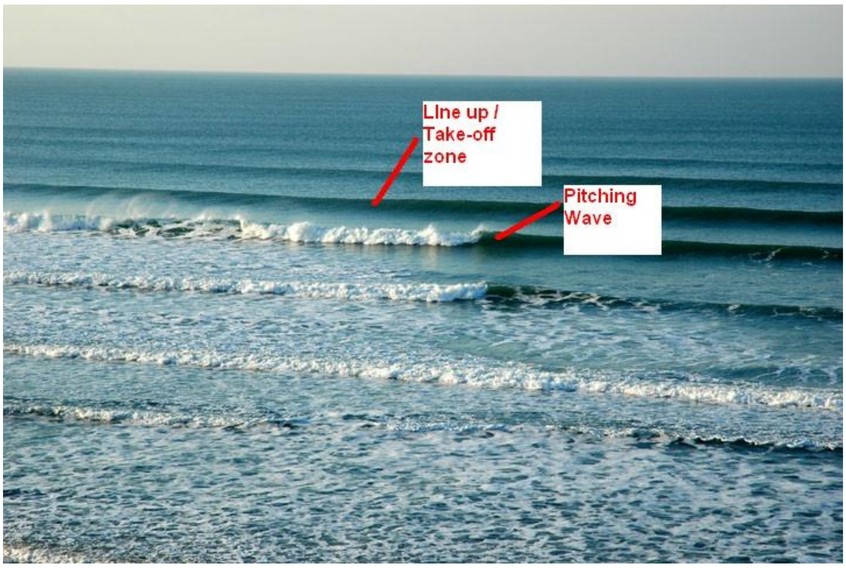

Figure 1.1 showing the take-off zone and pitching wave.

The process for both free surfing (leisure) and competition is the same. However competitions always involve a time constraint, for example 20 minutes per heat with surfers competing in an elimination process. The competition is scored by a panel of judges where points are awarded for technical difficulty and execution of manoeuvres ASP (2013).

The judging criteria state that, "*A surfer must perform radical controlled manoeuvres in the critical section of a wave with speed, power and flow to maximize scoring potential. Innovative / progressive surfing as well as variety of repertoire (manoeuvres, will be taken into consideration when rewarding points for waves ridden. The surfer who executes this criteria with the maximum degree of difficulty and commitment on the waves shall be rewarded with the higher scores*" (ASP 2013, page 58.).

Free surfing involves the same manoeuvres and techniques as competition surfing except there are no time constraints other than those dictated by the tides, waves and the surfers themselves. Personal observations indicate that surfers tend to use their free surfing time as a "training" opportunity where they can master and develop new skills and manoeuvres whilst maintaining their fitness levels.

1.1 Physical science perspectives of surfing.

Before this thesis investigates and discusses the nuances of the exercise physiology and performance aspects of surfboard riding it is important to discuss surfing and the environmental conditions which occur to create waves and the physical bathymetry which interacts with the waves to shape them into the medium where surfing is performed. This will help in understanding the action of surfing and the subtle differences between surfing waves in different locations, during different environmental conditions and at different times.

This section will attempt to explain the creation of waves and the shaping of these waves to make them suitable for different aspects of surfing; and in turn how these factors might influence the types of surfers using the waves and the type of surfing which might be performed.

1.1.1 Wave generation.

There are several stages in the generation of waves which can be surfed and the initial stage is caused by the action of wind blowing over the surface of the ocean. It is not completely understood how the energy from the wind is imparted into the surface of the water; however it is generally accepted that there are two main mechanisms involved. The initial stage of wave generation is the creation of little bumps on the surface of a completely flat sea called capillary waves. This happens as winds blow across the ocean surface direction of air flow is not purely horizontal and will contain tiny vortices of air which act in a vertical direction. The action of a downward stream of air will cause a tiny depression in the surface of the sea and bump where the wind is not acting. When the vortice no longer exerts a downward draft the surface will spring back upwards and the lump will spring back to its normal level due to the restoring force of the surface tension of the water and a small wave will propagate outwards (this can be seen if you blow gently downwards into your mug of coffee). If the vortices were to follow one of these waves then the wave might grow bigger and bigger as the vortices transmit more energy into it. The size of these capillary waves grows linearly with the length of time that the wind acts upon them; once the waves are ~ 1cm high the sea state will appear to have a certain roughness to it and is prepared for the second phase of wave growth (Butt and Russell, 2006). Once the capillary waves are created and the sea surface is no longer flat then the air flow over the surface becomes turbulent and creates turbulent eddies. These new larger vortices are not random like those involved with the creation of the capillary waves but are linked to the waves themselves and follow the waves along imparting more energy and increasing the size of the waves. These larger waves are referred to as 'gravity waves' as the restoring force is gravity. These waves will continue to grow as long as the wind acts upon them and therefore the height of the waves is determined by the length of time that the wind acts upon the waves, the distance over which the wind acts (fetch) and the strength of the wind acting upon them, with stronger winds being able to raise larger masses of water before the wave is restored by gravity.

The waves that have been generated in the area of the winds (near the storm) are constantly being supplied with energy by the wind and the sea will contain waves of varying lengths, sizes, shapes and directions all mixed together. This is called a windsea. However the waves will begin to propagate away from the generating area and travel without the influence of the overlying wind as free travelling 'swell'. Several changes to the swell will occur as it travels away from the generation area but the most important changes are:

Circumferential dispersion: the waves get smaller as they spread out over a larger and larger area.

Radial dispersion: is the separation of waves in a radial direction. Waves with longer wavelengths will travel faster than those with short wavelengths and so will arrive on distant shores first.

Grouping: throughout the propagation the waves will become sorted into 'sets' of waves of similar sizes travelling as a group.

The various stages of the wave generation can be seen in Figure 1.2 and these are described as follows (BSA 2007):

The wind blowing over the surface of the ocean causes ripples to form. If the wind continues these increase to form wind chop (small waves)

If the wind is strong enough and the fetch is sufficient then significant waves will be formed

As the waves travel further from the strongest area of wind they form swells which radiate out (downwind) from this area

Waves passing through water cause particles to rotate in a circular orbit. These orbits become smaller in diameter as the depth of water decreases

As swells reach shallower water they slow down, causing the wave length to shorten and the swell to peak up

When the swell reaches a certain depth of water (around 1.3 x height of the swell) the internal particles can no longer rotate and they pitch forward from the top of the wave i.e. the wave breaks.

The momentum of the breaking wave pushes water towards the shore. This broken wave (the soup) dissipates fairly quickly due to the friction involved.

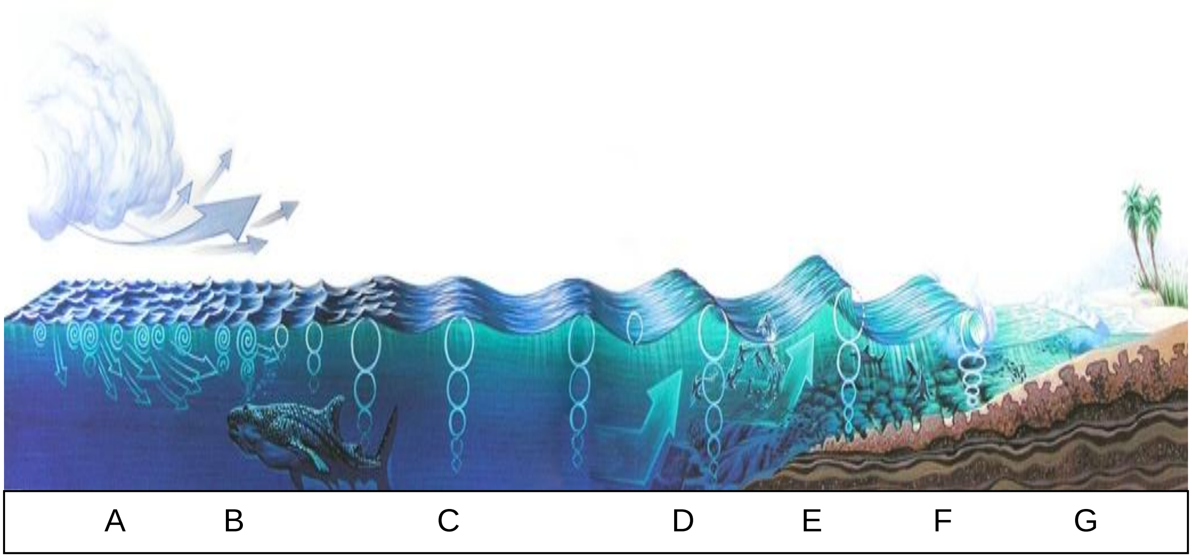

Figure 1.2 wave generation and propagation image adapted from Kampion and Brewer (1997)

1.2 Breaking waves

The previous section discussed the actions involved in wave generation or ocean travelling swell. The waves at this point are not 'surfable' in that they will be too long and will not have a 'wave face' on which to ride. To produce "surfable" waves the swell must interact with the underlying bathymetry of the coast.

Surfers generally desire a wave where the breakpoint "peels" along the wave crest, allowing them to surf just ahead of the breaking wave within the "wave pocket" where much of the wave's power is located. Generally surfers will not be satisfied with waves that do not peel unless they are a beginner (Scarfe *et al.* 2003). Waves can be simply termed "right or left-handers"; a "right-hander" is a wave that peels from left to right from the surfers perspective as they ride the wave and a "left-hander" does the opposite. Surfers will surf right and left handers in slightly different manners depending on whether they are a “regular” or “goofy” footed. When a surfer who is regular footed is riding a right hander they are said to be riding on their forehand (see Figure1.3) or they will be surfing facing the wave, when a regular footed surfer rides a left hander they are said to be riding on their “backhand” or will have their back facing the wave (see Figure1.4). A goofy footed surfer will ride a right hander on their back-hand (see Figure1.5) and a right hander on their forehand (see Figure1.6).

Figure 1.3 “Regular” right hand wave.


Figure 1.4 “Regular” left hand wave.


Figure 1.5 “Goofy” right hand wave.

Figure 1.6 “Goofy” Left hand wave.

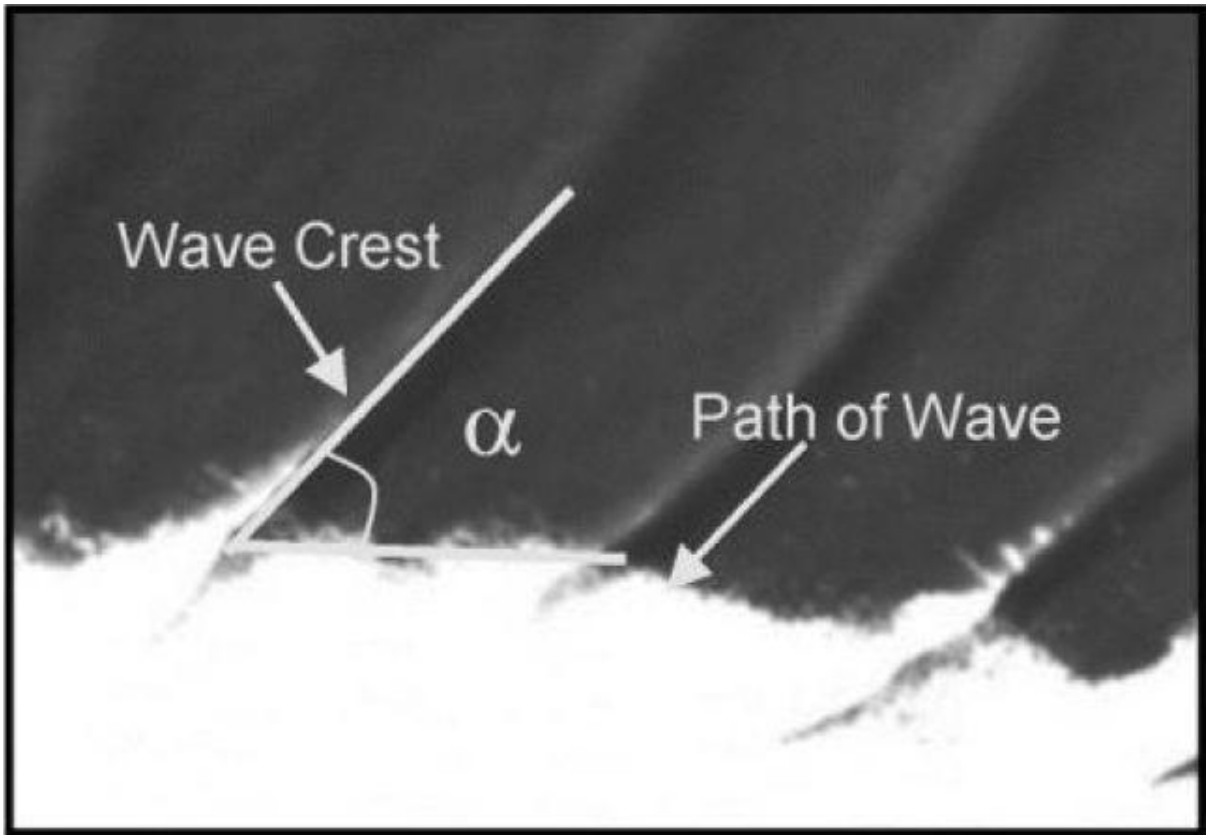

Figure 1.7 Peel angle (Scarfe *et al.* 2003).

According to Scarfe *et al.* (2003) the peel rate of the wave and the breaker type determine the skill level required to surf the wave and the types of manoeuvre's that can be performed. The peel rate is defined as the speed at which the breaking crest of the wave progresses laterally along the wave crest. Surfers must surf at least as fast as the peel rate in order to stay in front of the breaking point. The peel rate is directly related to the peel angle (α) of the wave, this is defined as the angle between the trail of broken white water and the crest of the unbroken part of the wave as it moves towards the shore (Figure 1.7). Peel angles vary between 0˚ and 90˚ with low angles creating fast surfing waves and large angles creating slow waves. A wave with a peel angle of 0˚ would be described as a close out and is not suitable for surfing except by beginners who wish to surf the white water that is produced.

However, the faster the peel rate the faster a surfer must surf and therefore the greater the skill level required. Hutt *et al.* (2001) developed a universal rating scheme of surfer ability that is based around the manoeuvres the surfers can perform and the characteristics of the waves that surfer can successfully surf (Table 1.1).

Table 1.1 Surfer skill rating (Hutt et al. 2001).

Rating	Description of rating	Peel angle limit (deg)	Min/max wave height (m)
1	Beginner surfers, not yet able to ride the face of the wave and simply moves forwards as the wave advances	90	0.7/1.00
2	Learner surfers able to successfully ride laterally along the rest of a wave.	70	0.65/1.50
3	Surfers that have developed the skill generate speed by ‘pumping’ on the face of the wave.	60	0.60/2.50
4	Surfers beginning to initiate and execute standard surfing manoeuvres on occasion.	55	0.55/4.00
5	Surfers able to execute standard manoeuvres consecutively on a single wave.	50	0.5/>4.00
6	Surfers able to execute standard manoeuvres consecutively. Executes advanced manoeuvres on occasion.	40	0.45/>4.00
7	Top amateur surfers. Able to consecutively execute advanced manoeuvres.	29	0.4/>4.00
8	Professional surfers. Able to consecutively execute advanced manoeuvres.	27	0.35/>4.00
9	Top 44 surfers. Able to consecutively execute advanced manoeuvres.	Not reach	0.3/>4.00
10	Surfers in the future	Not reach	0.3/>4.00

The Hutt scale of surfer skill rating (HSSR) rates the surfers on a scale of 1-10 from absolute beginners to the level of future professionals. This scale allows the general ranking of surfers in the absence of competitive ranking.

Often wave height is considered the most important factor for surfing (Raichle 1998), in the scientific study of surfing, wave height is measured from the crest of the wave to the wave trough. However, surfers make subjective measurements and will estimate wave size using different measurements with many surfers measuring the wave height on the face of the wave, but some – especially those from Hawaii measuring from the back of the wave (Guisado 2003). Other surfers will also use a more subjective form of assessment describing the wave height in relation to the surfer and assuming that the surfer crouching slightly ~5ft tall (see Table 1.2)

Table 1.2 Wave height and surfer description.

Wave size	Wave size Hawaiian scale	Subjective surfer height
1ft (0.3m)	0.5ft (0.15m)	Shin high
2ft (0.6m)	1ft (0.3m)	Knee high
3ft (0.9m)	1.5ft (0.45m)	Waist high
4ft (1.2m)	2ft (0.6m)	Chest / shoulder high
5ft (1.5m)	2.5ft (0.75m)	Head high
6ft (1.8m)	3ft (0.9m)	1ft overhead
8ft (2.4m)	4ft (1.2m)	3ft overhead or head and a half
10ft (3.0m)	5ft (1.5m)	Double overhead

Independent of the wave size surfers will also assess the wave breaking intensity (B_I) when deciding upon the quality of a surfing wave. Waves can be defined on a continuum from spilling, plunging, to surging or collapsing. A spilling wave can be described as a crumbling wave where the peak of the wave crumbles down the face of the wave. These waves are generally considered good for beginners. The plunging wave are the preferred type of surfing wave with a very steep wave face, the front of the wave might drop below sea level creating a wave face which is larger than the back of the wave and sometimes producing a “tube” or “barrel”. The surging wave does not break but surges up the beach. The collapsing wave is a wave which has a steep wave face but collapses; this wave is intermediate to the plunging and surging waves (Butt and Russell 2006).

The breaker type is produced through the interaction of the wave steepness and the beach slope; whereby “non-steep” (those with a longer period –“swell”) waves will surge or plunge on a steeply sloping beach, but steep waves (those with a short period – “chop”) on a gently sloping beach are more likely to be a spilling type wave. Komar (1998) suggests the use of the Iribarren number (ε_b) as a method of describing breaker type this is calculated as in equation 1.

Equation 1.

$$\varepsilon_b = \frac{tan\,\theta}{\sqrt{H_b/L_o}}$$

Where θ is the bed slope, H_b the breaker height and L_o the deep-water wavelength.

The breaker types are defined as:

<0.4 = spilling

0.4 – 2.0 = plunging

>2.0 = surging

The bathymetric profile of a beach will not be constant along the length of the beach thus the wave will not generally peel in a consistent manner but will break in sections creating interesting and challenging surfing conditions as the surfer can perform different manoeuvres on each section. The sections occur where there is a change in wave height, peel angle or breaker intensity (Scarfe *et al.* 2003).

The wind can also have a serious effect on the waves, if the wind is offshore it has the effect of “cleaning up” the swell /waves. This is the result of the off shore wind flattening out short period swell, leaving only the longer range “ground swell” and also the offshore wind physically holds up the wave and delays breaking. This causes the wave to break in shallower water and with much more intensity and the waves become steeper and more likely to tube (Butt and Russell 2006).

1.1.3 Types of break

The first and most common type of break in the UK (an area where waves break in a surfable manner) would be a beach break. The beach break is characterised by waves breaking on an open beach, generally over a sand bottom. If the beach slopes steeply this can create powerful hollow waves (see Figure 1.8), whereas if the beach slopes gently it might produce weak / slow waves. The waves will break in right or left directions depending upon the sand banks and the swell direction, the nature of the wave will change as the waves / currents erode or build sand banks upon which they are breaking.

Figure 1.8 Beach break, Cornwall, United Kingdom.

The second main type of break is a reef break. The reef break occurs where waves travel out of deep water onto a shallow “reef”. In tropical areas it is most likely that this will be a coral reef whereas here in the UK the reef is most likely to be of rock / stone. As the wave is travelling from deep water onto a solid bottomed shallow water area the waves tend to break in a powerful manner (Figure 1.9). Reef breaks can be affected massively by the tide; being dry at low tide or too deep to break at high tide.

Figure 1.9 Reef break (Devon, United Kingdom).

The third main type of surfing break is the Point break, this occurs where a wave breaks along the shallow water of a point of land. The point break can be over either a sand or reef bottom but they tend to break consistently in the same direction giving comparatively long rides. Also due to deep water off the headland the paddle out is often comparatively easy or alternatively surfers can sometimes exit the water after a ride and simply walk up the point and re-enter beyond the surf zone (see Figure1.10).

Figure 1.10 Point break (Lynmouth, United Kingdom).

The factors which must combine to provide good surfing waves are multiple and constantly changing: for example when a wave breaks upon a sand bar it will change that bar slightly by eroding some of the sand thus making the next wave interact in a slightly different manner; however the second wave of the set will not be exactly the same height / shape as the first in any case. Add to this the effect of wind gusts, tides, backwash etc and it becomes clear that surfing conditions within any given session are not consistent and that conditions will vary by the minute or hour. These factors make the quantitative assessment of the physiological response to surfing very difficult and where measurements have been taken these will only be representative of the mean response over the period of the experiment and the conditions in which they were measured should be considered when evaluating the data.

1.2 Physiological and performance perspectives of surfing

Meir *et al.* (1991) performed a motion analysis of one hour of recreational free surfing using recreational surfers (n=6, age = 21.2 ± 2.8 years, body mass = 68.9 ± 5.7Kg) who had all previously competed at state level in Australia. During the study, the subjects were monitored by video and heart rate was also recorded by heart rate monitor. Before the subjects participated in the one hour of recreation surfing they were subjected to an incremental $\dot{V}O_{2peak}$ (peak oxygen uptake) exercise test. The Meir (1991) study was performed using a Repco swim bench ergometer and involved a protocol which used incremental workloads starting at 25W, increasing by 25W each minute. Gas analysis was performed using closed circuit spirometry. A calibration model for $\dot{V}O_2$ was developed from the heart rate and $\dot{V}O_2$ data from the laboratory test to allow for the estimation of energy expenditure during surfing performance and the results of Meir *et al.*'s (1991) study indicated that surfers spend the most time paddling their surfboard either to the line-up or attempting to catch a wave, which accounted for 45% of total time. Waiting in a stationary position for a suitable wave accounted for the second largest percentage of total time at 35%. Miscellaneous activities such as "duck diving" under white water, wading and swimming when "caught inside" accounted for 16% with wave riding accounting for only 5% of the total time observed. Meir *et al.* (1991) found that the mean heart rate during the session was 75% of the maximum heart rate (HR) obtained by the surfers in a previous incremental swim bench based exercise test (HR_{labmax}). Furthermore the peak heart rate attained while surfing was 95% of HR_{labmax} with mean heart rates for paddling and while stationary representing 80% and 71% of HR_{labmax} respectively. The data derived from the incremental exercise test produced a mean $\dot{V}O_{2\,peak}$ of 3.8 ± 0.8 $L.min^{-1}$ with the mean oxygen cost during surfing being 2.8 ± 0.5 $L.min^{-1}$. This equated to an energy cost of 2077.0 ± 322.1 $kJ.hr^{-1}$.

Mendez-Villanueva & Bishop (2005) described data from a study which monitored HR during a simulated 20 minute competition heat. Apparently an incremental lab based test was performed before the simulated heat to ascertain peak heart rate and $\dot{V}O_{2\,peak}$. The study found that the average HR during the heat was 146 ± 20 beats per minute, which represented 84% of the peak heart rate achieved in the laboratory. Overall the male surfers spent 25% (5 minutes) during the heat above 90% of their HR_{peak}. Mendez-Villanueva & Bishop (2005) speculated that the results showed the surfers performed periods of moderate exercise and recovery utilising the aerobic system, interspersed with bouts of high intensity exercise demanding both aerobic and anaerobic metabolism. However the numbers of subjects and their physical parameters such as age, height and body mass were not published, thus making useful comparisons impossible.

More recently Mendez-Villanueva *et al.* (2006) analysed the activity profile of 42 experienced, elite level professional male surfers participating in the 2003 World Qualifying Series (WQS) 6 star Salomon masters international surfing tournament in Western Australia. During the observation the environmental conditions were observed with light offshore winds being predominant, although some heats were held with light onshore winds. The wave heights during the observation were stated as 1 to 2m although it is not clear how these were measured. The study found that during competition the percentage of total time devoted to paddling, remaining stationary, wave riding and miscellaneous activities was 51.0%, 42.5%, 3.8% and 2.2% respectively. The values reported for time spent paddling and remaining stationary were higher than those reported by Meir *et al* (1991). Mendez-Villanueva *et al.* (2003) proposed that the differences in temporal relationships in comparison to the Meir *et al.* (1991) study were merely the result of the demands of free and competition surfing. It should be considered that the variation in these values could be due to the surf characteristics such as consistency of the surf, type of break (beach break, reef break, point break) or indeed tactical considerations by the athletes during competition. It was noted that the average length of ride in the study (11.6 seconds, CV=61.4%) was lower than that of rides recorded in a report by Lowdon *et al* (1996) who reported average values of 23.7 seconds (S not reported). This difference might be due to the judging criteria in effect in the 1996 study, where the criteria required the execution "of the most radical controlled manoeuvres, in the most critical section, with the most speed and highest degree of difficulty for the longest functional distance"(Lowden *et al.* 1996, page1.). The criterion of "longest functional distance" has now been removed allowing surfers to ride shorter waves whilst still fulfilling the other judging criteria. This might partially explain the differences in length of ride observed by Mendez-Villanueva *et al.* (2006) and Lowden *et al.* (1996).

Most recently Farley *et al.* (2012) performed video analysis, heart rate measurement and GPS monitoring of 12 national standard male surfers. In total 32 individual surfing sessions were analyses. The analysis was performed during a 20 minute competitive heat at two different events. The first event was performed at a beach break with waves of 1.2-1.5m "face height" and the second event was a point break with consistent 1.5m faces. Differences were found between the two events in the analysis and the values averaged across the sessions. Farley *et al.* (2012) recognised the effect of wave conditions and breaker type in their analysis but did not seek to explain the effects; as such only the data averaged across the two sessions was numerically presented. The study found that on average paddling was performed for 54% of the total time which is higher than both of the previous studies (Meir *et al.* 1991, Mendez-Villanueva *et al.* 2006). Time spent stationary was lower than the previous studies (Meir *et al.* 1991, Mendez-Villanueva *et al.* 2006) at 28%. The times spent paddling for a wave (sprint paddling), surfing and miscellaneous activities were 8%, 5% and 16% respectively which are similar to the results of Meir *et al.* (1991) for wave riding and miscellaneous activities. The values of Farley *et al*. (2012) were higher than the 3.8% of total time spent surfing and 2.5% of total time spent during miscellaneous activities during the Mendez-Villanueva *et al.* (2006) study. These variations might due to the differences in ability of the surfers or the differences in the conditions determined by the wave size and location. Farley *et al.* (2012) argue that the large portion of time spent paddling was the result of the surfers having to travel back to the line-up after riding a wave and that possessing high aerobic capacity would allow the surfers to paddle back out to the line-up more readily and therefor catch more waves or provide options for catching set waves with higher scoring potential and increase their scoring capacity. The GPS data from the Farley *et al.* (2012) study supports the video analysis in that 58 ± 10% of the time was spent in a low speed zone of 1.0-4.0km.h^{-1} which was attributed to the large portion of time spent paddling (54%). The second largest amount of time (29 ±

5.5%) was spent between 4.1 and 8.0km.h^{-1} which was determined as sprint paddling. The average speed was determined as 3.1 ± 0.6 km.h^{-1} with an average maximum speed of 33.4 ± 6.5 km.h^{-1}. In terms of distances covered it was found that on average the surfers covered 1605.0 ± 313.5 meters in 20 minutes of which 947.0 ± 185.6 meters was spent paddling and 128.4 ± 25.0 meters was spent wave riding.

The wave and swell sizes reported by Farley *et al*. (2012) offer some insight into the nature of the surfing session and it is possible to ascertain that the reported differences in time spent in each activity, and the distances travelled have been affected by the different locations such as the beach break and the point break. It is not clear how changes in the conditions have affected the surf as the waves in the second test at the point break were consistently 1.5m whereas the waves at the beach break were ranging between 1.2 and 1.5m. If the waves at the beach break had been consistently 1.5m it is not clear that any differences would have been evident. The maximum riding speeds are also presented as an average of the two locations however it would have been interesting to identify how the maximum wave speed differed between both the two locations and the wave consistencies, since the thoretical maximum surfing speed is related to the size of the wave (Dally 2001).

The heart rate data presented by Farley *et al.* (2012) suggested that peak heart rate were achieved a when the surfers completed their rides. It had been expected that the peak heart rate would be achieved during the sprint paddling for waves but it was determined that the effect of the demand of riding the wave, adrenaline release associated with the riding or falling from the wave, breath holding and "heart rate lag" overrode this (Achten and Jeukendrup 2003). The surfers were found to spend 60% of their total time with heart rates between 56% and 74% of the maximum measured during laboratory testing with a mean heart rate of 140 ± 12 beats.min^{-1} or 64.4% of maximum heart rate.

There is little additional published research explaining the demands of surfing with no research analysing how conditions such as wave size, quality and weather conditions or interaction between participants might affect the temporal and physiological parameters of the activity.

1.3 Purpose of this thesis

Thus far we have a relatively clear understanding of how the waves that are used for surfing are produced and shaped through the interaction of metrological phenomena, water and near shore bathymetry. There is also a growing body of work that describes the physiological (fitness) parameters associated with adult surfers of varying ability and also descriptions of the performance parameters and physiological responses to surfing activity. However currently no literature exists relating to the variation in anthropometric profiles of surfers; how talent might possibly be identified in young surfers, how surfing performance might be improved through supplementation or how the physiological and performance parameters of surfing might change as wave conditions or ability of the surfers change.

Chapter 2.0 Study 1 Anthropometric variables and their relationship to performance and ability in male surfers.

Some of the data from this chapter formed the basis of the presentation "Anthropometric measures and prediction of competitive national rank in male high performance junior British surfers" presented at the 2008 BASES annual conference at Brunel University. An abstract of which was published in Journal of Sports Sciences, 26: 1, S1 — S143. Copies of the Abstract and Poster can be found in appendices 2 and 2.1 respectively.

This chapter also formed the basis of the published paper Barlow, M.J.; Findlay, M.; Gresty, K; and Cooke, C.B Anthropometric variables and their relationship to performance and ability in male surfers. (19th March, 2012) epub ahead of print. European Journal of Sports Science. A copy of which can be found bound in to this thesis.

2.1 Introduction

"Studies in a variety of sports have indicated that, unless one has a distinctive and specific body form suitable to the sport, there is little likelihood of success in top class performance" (Lowdon, 1980, page 34).

Anthropometry refers to the measurement of the individual human body for the purpose of understanding human physical variation. The history of the development of anthropometry is diverse and many aspects of its development were of sinister origins. Alphonse Bertillion (1893) developed a system of identification based on elements of the human frame which remain largely constant through life. These methods were then employed by the police for identifying repeat criminal offenders. The measurements were developed and employed by Francis Galton in his studies of eugenics and the eugenics programmes in the United States of America and famously Hitler employed anthropometric measures to distinguish between Aryans and Jews during the Holocaust in Nazi Germany (Heinrichs and Hargrove 1987).

In recent times anthropometry and body composition assessments have been used within the health and fitness fields to assess the general health status of individuals and by insurance companies to assess risk for life insurance policies (Mc Ardle et al. 2007). The interest in anthropometry and body composition relating to sports performance is based on the finding that there are specific physical characteristics in various sports that predict whether the performer would be able to compete at the highest levels in that sport (Lowdon 1980, Lowdon and Pateman 1980, Goldsmith et al. 1987, vanSonnenberg et al. 1987, Withers and Kenworthy 1987, Bourgois et al. 2001).

2.1.1 Anthropometry and body composition assessment methods.

Human structure can be explained in terms of increasing organisational complexity ranging from atoms and molecules to the anatomical level which can be described as a hierarchy of cell, tissue, organ, system and organism. At a reference level anthropometry and body composition is the quantification of anatomy and can be approached at any of these levels dependent upon what is of interest (Hawes and Martin 2001).

The definition of these levels has been the focus of some ambiguity with authors referring to the components using various terminology for example are 'lipid free mass', 'fat free mass' and lean 'body mass the same thing'? Wang et al(1992) developed a five-level model that provided a structural framework that went beyond an individual compartment or level (Figure 2.1)

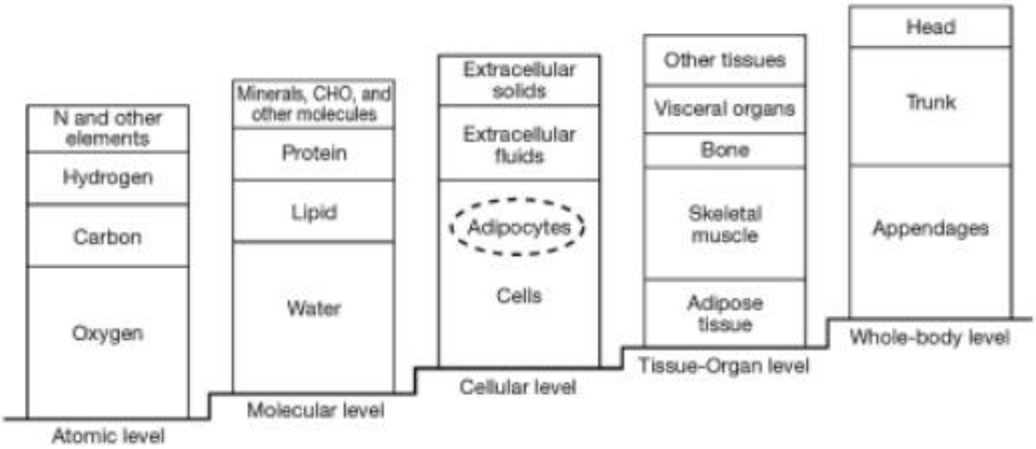

Figure 2.1 The five-level model of body composition (Heymsfield et al. 2005) .

2.1.2. Level 1 – The atomic level of body composition

At the atomic level the human body is made up of atoms or elements with >98% of total body mass arising from jut six elements: oxygen, carbon, hydrogen, nitrogen, calcium and phosphorus, the majority of the remaining <2% is formed from sulphur, potassium, sodium, chlorine and magnesium with 39 other elements that each contribute less than 0.2% of body weight (Snyder et al. 1984, Heymsfield et al. 1991). Traditionally elemental analysis has been performed using cadaver studies or in biopsy from selected organs and tissues and might be useful for assessing the impact of disease or generic population measures but has limited relevance to sports performance.

2.1.3 Level 2 – The molecular level of body composition

The elements that make up the human body at the atomic level are combined to form over 100,000 various chemical compounds within the human body; it is not currently possible to measure all of these compounds nor would it be useful to do so and thus these compounds are categorised into water, lipid, protein, mineral and glycogen (Wang et al. 1992). Body weight (Bwt) can be defined as (Wang et al. 1992):

Bwt = lipid + water + protein + mineral + glycogen + residual chemicals

Bwt = water + dry mass

Bwt = lipid + lipid free mass

Bwt = fat + fat mass

Of the five components of the molecular model currently only water and mineral can be measured directly at the molecular level. Water can be directly measured at the molecular level using a variety of techniques such as dilution techniques (Wang et al. 1992), quantitative magnetic resonance (Taicher et al. 2003, Tinsley et al. 2004) and bioelectrical impedance analysis. Mineral can be assessed using dual X-ray absorpiometry (DEXA) (Lohman and Chen 2005, Lee and Gallagher 2008). Lipid, protein and residual chemicals require indirect estimation using measurements at other levels (Wang et al. 1992); for example protein can be estimated by measuring nitrogen at the atomic level and assuming that all nitrogen in the body is contained within protein and that 16% of protein is nitrogen (Heymsfield et al. 1991).

2.1.4 Level 3 –The cellular level of body composition

The elements of the molecular level are organised within the cells of the human body. It is the coordination and integration of the actions of these cells that underlies the function of the human body (Wang et al. 1992); At the cellular level the human body is composed of three main components – cells, extracellular fluid and extracellular solids. Of the three compartments at this level only extra cellular fluid can be measured through dilution techniques or bioelectrical impedance analysis (BIA), the other compartments must be estimated through measurements at other levels (Lee and Gallagher 2008). Although the cellular level is theoretically of great importance (as it links the function of the human body to the inanimate elements that it is comprised of); there is little research concerned with the study of body composition at this level due to difficulty in quantifying the cellular compartments (Wang et al. 1992).

2.1.5 Level 4 – The tissue level of body composition

The fourth level of organisation includes the tissues, organs and systems which regardless of various levels of complexity are simply arrangements of tissues (Hawes and Martin 2001). The tissues are categorised as connective, epithelial, muscular and nervous (Jacob et al. 1978). Around 75% of the total body mass is represented by the connective tissues which include bones, adipose and muscle (Snyder et al. 1984). The adipose tissues are constituted of adipocytes together with collagen and elastin fibres. The greatest deposits of adipose tissue are found in the subcutaneous region but it is also found in smaller quantities surrounding organs, within tissues such as muscle fibres and within yellow bone marrow (Snyder et al. 1984).

There is no direct measure of adipose tissue at the tissue level but medical imaging technology such as ultrasound, magnetic resonance imaging and computed tomography allow estimation of adipose and other tissues in cross sectional images of the body (Wang et al. 1992, Hawes and Martin 2001, Lee and Gallagher 2008, Ackland et al. 2012). Bone is a type of specialised connective tissue which is made constituted of an elastic protein matrix onto which a calcium phosphate mineral is deposited providing strength and rigidity this can be measured using dual energy x-ray absorptiometry which is the “gold-standard” method of assessing for osteoporosis and osteopenia (Wang et al. 1992, Hawes and Martin 2001, Lee and Gallagher 2008). Muscle tissue is found in three forms, skeletal, visceral and cardiac but there are few methods for the assessment of muscle although magnetic resonance imaging and spectroscopy appear to be the most promising (Hawes and Martin 2001, Lee and Gallagher 2008).

2.1.6 Level 5 - The whole body level of composition

The Whole body of composition is primarily concerned with body size, shape and exterior characteristics and these are measured through the ten dimensions of stature, segment lengths, body breadths, circumferences, skinfold thicknesses body surface area, body volume, body weight, body mass index and bone density (Lohman et al. 1988, Wang et al. 1992). Table 2.2 outlines the levels and components of body composition assessment (Lee and Gallagher 2008).

Table 2.1 Representative multicomponent models at the five-body composition levels (Heymsfield et al. 2005).

Level	**Body composition model**	**Number of components**
Atomic	BM = H + O + N + C + Na + K + Cl + P + Ca + Mg + S	11
Molecular	BM = FM + TBW + TBPro + Mo + Ms + CHO	6
	BM = FM + TBW + TBPro + M	4
	BM = FM + TBW + nonfat solids	3
	BM = FM + Mo + residual	3
	BM = FM + FFM	2
Cellular	BM = cells + ECF + ECS	3
	BM = FM + BCM + ECF + ECS	4
Tissue-organ	BW = AT + SM + bone + visceral organs + other tissues	5
Whole body	BW = head + trunk + appendages	3

AT, adipose tissue; BCM, body cell mass; BM, body mass; CHO, carbohydrates; ECF, extracellular fluid; ECS, extracellular solids; FFM, fat-free mass; FM, fat mass; M, mineral; Mo, bone mineral; Ms, soft-tissue mineral; SM, skeletal muscle; TBPro, total body protein; TBW, total body water.

2.1.7 Methods of body composition assessment in sport and exercise settings.

Many different techniques exist for the analysis of body composition and these can be categorised as ‘reference’, ‘laboratory’ and ‘field’ techniques (Ackland et al. 2012). The ‘reference’ techniques represent the criterion against which other techniques are compared; however these techniques might have limited application for monitoring athletes due to various reasons such as feasibility e.g. (cadaver dissection), expense (e.g. magnetic resonance imaging), lack of normative data (e.g. multi component models) and unnecessary radiation exposure (computed tomography) (Ackland et al. 2012).

2.1.8 Laboratory Techniques.

Laboratory techniques are used extensively to assess the body composition of athletes but there is a wide range of variation in their accuracy and precision. Dual energy X-ray absorptiometry (DEXA) has been used extensively for the assessment of osteoporosis and is increasingly used for the assessment of soft tissue (Hawes and Martin 2001, Ackland et al. 2012). DEXA works by passing a collimated dual energy x – ray beam through the participant who is lying supine on the machine. The nature of the tissue is determined by the absorption of the x-ray beam and quantified as bone, fat mass and fat free mass (rather than muscle). The validity of DEXA to accurately assess body composition is relatively well documented and its ease of use compared to other laboratory measures mean that it is increasingly used within sports related studies and monitoring athletic populations (Going et al. 1993, Avlonitou et al. 1997, Madsen et al. 1997, Wang et al. 1999, Hawes and Martin 2001, Kim et al. 2002, Mattila et al. 2007, Veale et al. 2010, Ackland et al. 2012). However there are some practical issues that might limit the use of DEXA within athletic populations – due to the nature of the of the calibration models used by DEXA manufacturers participants who are excessively, large, small or lean might introduce errors and many models will not accommodate individuals taller than 192 cm (e.g.

basketball players) or heavier than 120kg (e.g. rugby players) (Ackland et al. 2012). Furthermore the cost of a DEXA scanner (~£50,000) make them unobtainable for many small research units or individuals.

Densitometry is the measurement of body density (Db) which is performed by either underwater weighing or air displacement plethysmography (Ackland et al. 2012). These approaches use a two compartment model of fat mass and fat free mass which are calculated from the measurement of whole body density (Keys and Brozek 1953). Underwater weighing is based upon the Archimedes principle which states that the upthrust on a body that is fully submerged is equal to the weight of water that the body displaces. Thus, the weight of the water displaced by the body is equal to the weight of the body in air minus its weight in water and by dividing the resultant value by the density of water we can calculate the gross volume of the body (Hawes and Martin 2001). Underwater weighing relies on suppositions regarding the density of both the fat mass and fat free mass compartments with the density of the fat mass being assumed to be constant as that of triglyceride at 0.900 g.ml-1 which is generally accepted (Hawes and Martin 2001). However there is great debate over the appropriate density used to measure fat free mass. Many equations use the original value of 1.100 g.ml-1 proposed by Behnke et al(1942) however this has been acknowledged as merely an estimate (Keys and Brozek 1953) and in the absence of a directly validated measure has remained in use by many researchers. Martin and Drinkwater (1991) estimate the standard deviation in fat free mass density to be 0.02 g.ml-1 thus dependant on the equation used to estimate the body fat percentage can create significant errors. Hawes and Martin (2001) give the example that If a lean male has a whole body density, Db = 1.070 g.ml-1 , then estimated body fat by Siri`s equation will be 12.6%. However if his fat-free density is actually 1.120 g.ml-1 rather than the assumed density of 1.100 g.ml-1 then this would result in 43% underestimate of fat free mass or if his fat-free density was actually 1.080 g.ml-1 then his fat-free mass would be overestimated by 168%. These factors can be exacerbated through variations of fat-free density related to ethnicity , athletic population and reduce the validity of this method as a reference model (Schutte et al. 1984, Ackland et al. 2012).

Air displacement plethysmograpghy (ADP) works on the same principle as underwater weighing without the need to submerse the participant in water. The system consists of two chambers; the test chamber where the participant sits and the references chamber which are separated by a vibrating membrane that induces pressure changes in the vessels. The changes in pressure in the vessel allow for the determination of the volume of air in that chamber – firstly without a participant and then with the participant with the difference between the values representing the volume of the participant (Hawes and Martin 2001). There are various threats to the validity of ADP such as air trapped between garments and the body or in body hair and the effect of subject positioning which combined with the suppositions relating to the density of fat free mass mean that values of body fat percentage derived from this method should be treated with some caution (Peeters and Camel 2001, Peeters and Claessens 2009, Ackland et al. 2012, Peeters 2012).

Other lab based methods such as ultrasound imaging and three dimensional photonic scanning exist but due to their relatively low levels of usage within sport setting they will not be discussed further within this thesis. Instead the review will focus on the field based assessments which are of direct relevance to this study. However the aforementioned methods required explanation as they often act as criterion methods for the validation of the field methods.

2.1.9 Field Techniques.

Skinfold measurements are one of the most widespread methods of estimating body fat within the sports performance setting with many body fat prediction equations having been developed (Lohman et al. 1988). The skinfold method measures the thickness of a double skinfold using calibrated callipers that exert a constant pressure over a range of thicknesses. The assumption is then made that by measuring the largest fat depot namely the subcutaneous depot we can make a reasonable estimate of total body fat (Hawes and Martin 2001). When measuring a single skinfold and relating the direct measure of the distance between the jaws of the calliper to a percentage fat value we are assuming that a compressed (by the calliper) double layer of skin and subcutaneous adipose is the equivalent of a single layer of uncompressed adipose tissue and that skin thickness is negligible or at least constant and that adipose tissue compresses in a consistent manner (Martin et al. 1985). The lipid content of the adipose tissue must also be assumed to be stable if a meaningful relationship between the skinfold thickness and body fat is to be derived however studies such as by Orpin and Scott (1964) have found considerable variation in the fat content of adipose tissue between 5.2% and 94.1% with Martin et al(1994) suggesting a general value between 60.0 & 85.0%. All of the above factors affect the validity of an individual skinfold measurement and further assumptions are made skinfold measures are taken in multiple sites and then used to calculate a predicted body fat measurement. Firstly it is assumed that the skinfold thicknesses at specific sites are representative of the subcutaneous adipose tissue around the body regardless of individual adipose patterning, second it is also assumed that the subcutaneous adipose tissue is reflective of total body fat including visceral fat (Hawes and Martin 2001).

Further the above inherent threats to the validity of skinfold measurements can be inadvertently affected through methodological inconsistencies for example varying the location of the skinfold measure by 1 cm from the International Society for the Advancement of Kinanthropometry (ISAK) specified location leads to significant differences in the value obtained (Marfell-Jones et al. 2006, Hume and Marfell-Jones 2008). In order to reduce measurement error through variations in technique ISAK developed guidelines in order to standardise the location of measurements and the procedures required to perform anthropometric measures such as skinfolds, body girths, bone breadths and lengths, body mass, and stature. Adherence to the ISAK guidelines and the practitioner training associated with individual ISAK accreditation seek to maintain intra-tester variation between measures to less than 1% for body mass, stature, girths and breadths with variability of less than 5% for skinfolds with inter-tester variation of 2% and 10% respectively (Marfell-Jones et al. 2006). Due to the relatively inexpensive nature of skinfold measurements they are widely used within the sports performance setting however it is important to select the most relevant equation for the prediction of body fat for the population being studied. Due to the variation in the skinfold equations, the assumptions in the equations and the possibility that there might not be a suitable validated equation for a specific population some authors (Marfell-Jones 2001) advocate the use of skinfolds as a surrogate for adiposity where the individual site values and sum of the skinfolds can be compared to those of high performance athletes where published (Norton et al. 2000).

Triceps, subscapular, supraspinale, and medial calf skinfold measurements can be combined with height, mass, humerus breadth, femur breadth, upper arm flexed and tensed girth and calf girth to give a measurement called the somatotype (Duquet and Carter 2001). The somatotype is a quantified description of the morphological appearance of a person that is presented as a three numeral rating e.g. 3.2 – 5.1 – 1.2 the three numerals represent endomorphy, mesomorphy and ectomorphy respectively. Endomorphy is the relative fatness of the individual irrespective of the distribution of the adipose tissue and incorporating the general roundness of the body, softness of the features, the relative volume of the abdominal trunk and the distally tapering of the limbs. Mesomorphy is a description of the relative muscularity of the individual and it also incorporates aspects such as the robustness of the physique in terms of muscle or bone and the size of the chest / shoulders. Ectomorphy is the description of the relative linearity of the body and the slenderness of the limbs, absence of muscle or adipose tissues (Carter 1980).

2.1.10 Anthropometry and sports performance

There have been several studies in which the anthropometric characteristics of various athletes have been evaluated, with inferences drawn between common body types and composition with performance for various sports such as running, soccer, volleyball, rugby league. mountain biking and rock climbing (Landers et al. 2000, Reilly et al. 2000, Bourgois et al. 2001, Watts et al. 2003). Such investigations have also been performed for surfing (Lowdon 1980, Felder et al. 1998) suggesting that surfers in the 80`s and 90`s were shorter and lighter than age-matched sporting populations, with mean male somatotype scores (mean ± s) of 2.6 ± 0.7 for endomorphy, 5.2 ± 0.9 for mesomorphy and 2.6 ± 0.8 for ectomorphy (Lowdon 1983). Lowdon`s (1983) study was based on a sample of 76 male surfers competing at collegiate level (from various racial and national backgrounds). Lowdon investigated whether there were any differences in body composition between the first 12 placed competitors and the first 20 placed competitors and the remainder of competitors using a student's t-ratio. No significant differences (P>0.05) were observed between the somatotypes of the groups and thus it was concluded that ranking order was not related to somatotype. Since Lowdon`s (1983) work the judging criteria in surfing competitions have evolved to focus less upon length of ride and more on the performance of specific manoeuvres. It is possible that these rule changes, especially the evaluation of speed and power of manoeuvre might have affected the representative physiological characteristics of successful modern competitive surfers. Bale (1980) identified that there was a relationship between anthropometric measures of muscularity such as mesomorphy, and dynamic strength and power. Speed and power are identified as key aspects of the judging criteria relating to execution of manoeuvres and have been identified as key parameters for the performance of functional surfing actions within surfing such as the "pop-up" (Eurich et al. 2010). Upper body strength has been found to be significantly related to sprint surfboard paddling speed in competitive male surfers (Sheppard et al. 2012).

Given that it is based upon the application of a universally accepted set of criteria by a panel of expert judges, performance in surfing can be best measured through competition success. However the majority of surfers do not compete so measurement of their performance rests upon assessing ability to perform specific manoeuvres consecutively and the ability to deal with waves of varying height, breaking speed and "peel angle". Hutt, Black, & Mead, (2001) developed a basic method for quantifying the surfer skill required for various types of wave conditions, which is often used as a parameter for consideration when developing artificial surfing reefs by coastal oceanographic scientists (Hutt et al. 2001) and can be used as an accepted method for assessing a range of surfing abilities. The rating system involves a 10 point scale that differentiates surfers by the manoeuvres they can perform, their peel angle limit and the minimum and maximum wave height in which they can successfully surf. The bottom of the scale is rated as level 1 - beginner surfers, not yet able to ride the face of the wave that simply moves forward as the waves advance; a peel angle limit of 90˚ and a minimum/maximum wave height of 0.7/1.00m. Level 9 of the rating refers to "top 44 surfers" who are able to consecutively execute advanced manoeuvres, are not limited by peel angle and can successfully surf waves of 0.3/>4.0m of height. Level 10 was reserved for surfers that surpass current standards (Hutt et al. 2001).

The aim of this study was to evaluate the anthropometric profiles of surfers and to identify any anthropometrical factors which might predict performance and ability in surfing.

2.2 Methods

2.2.1 Participants

Following institutional ethical approval 80 male surfers participated in this study (Appendix 1.0 and 1.1). The sample comprised of three sub-groups: 17 professional male surfers (mean age: 34.1 ± 3.8 years) were recruited at an International World Qualifying Series (WQS) 5 star event (2009). These surfers were likely to train rigorously and compete regularly in high level surfing competitions. Sixteen junior male (mean age: 15.6 ± 1.1 years) were also recruited from a national team who were training to attend the World Surfing Games. A further group of 47 male intermediate surfers were recruited from the student population at the University of Plymouth (mean age: 22.5 ± 2.8 years). Informed assent for minors (Appendix 1.2) and consent from adults (Appendix 1.3) was obtained before testing.

2.2.2 Procedures

All measures were taken by the author who was accredited (level 1) by the International Society for the Advancement of Kinanthropometry (ISAK). All measures were taken in accordance with the guidelines (Marfell-Jones et al. (2006)) on the right hand side of the body regardless of handedness or stance. As such measurements were taken twice and it was ensured that variation between measures was less than 1% for body mass, stature, girths and breadths with variability of less than 5% for skinfolds before recording. The tester`s Technical Error of Measurements (TEM`s) can be found in Appendix 1.3.

The stretch stature technique was used for the measurement of stature, the subject stands with the feet together and the heels, buttocks and the upper part of the back touching the scale of the stadiometer (Seca 225, Birmingham UK). The head was placed in the Frankfort plane (see figure 2.1) when the orbitale (lower edge of the eye socket) is in the horizontal plane with the tragion (the notch superior to the flap of the ear). The assessor places their hands along the jaw of the subject with the fingers pressing into to mastoid processes. The subject is asked to take and hold a deep breath, while keeping the head in the Frankfort plane the measurer applies a firm upward lift through the mastoid processes. The recorder places the headboard / plate firmly down on the vertex, crushing as much hair as possible. The recorder ensures that the subject's feet do not come off the floor and the measurement is taken to the nearest 0.1cm.

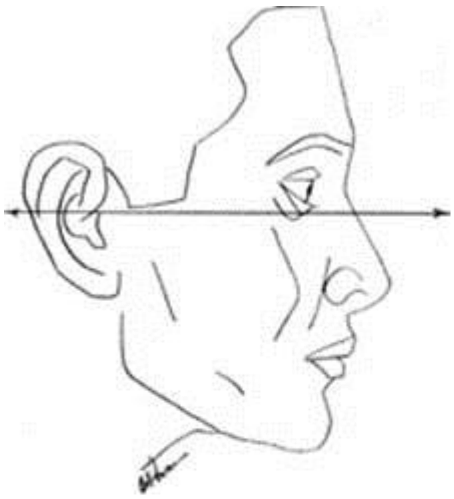

Figure 2.2. The Frankfort plane (Marfell-Jones et al. 2006).

Body mass was measured to the nearest 0.01kg using a digital scale (SECA 770, Birmingham UK). Body mass was measured by weighing the subject in minimal clothing i.e. swim suit or shorts and later weighing the clothing and deducting this from the total mass. Biepicondylar humerous and femur breadths were measured using a Holtain anthropometer (Holtain Ltd, Dyfed, UK) to the nearest 0.1cm in the manner described by Norton & Olds (2004).

Girths of the upper arm, waist, gluteal (hip) and calf were measured using an anthropometric tape (Lufkin W606PM, Cooper Hand Tools, Tyne & Wear, UK). The upper arm girth was measured both in a relaxed condition and also flexed and tensed. The relaxed girth was with the arm slightly abducted from the body. The measurement was taken at the marked level of the mid-acromiale-radiale. The flexed and tensed measurement was taken at the point of peak girth of the muscle when contracted. The waist girth was measured at the narrowest point between the lower costal (10th rib) border and the iliac crest: the measurement is taken with the arms slightly abducted and at the end of a normal expiration. The assessor stands in front of the subject to take the measurement and ensure the correct identification of the narrowest point. If there is no obvious narrow point then the midpoint between the lower costal and iliac crest is used. The gluteal (hip) girth is taken at the point of the greatest posterior protuberance of the buttocks which often corresponds anteriorly to the approximate level of the symphysis pubis (Marfell-Jones et al. 2006). The calf girth was measured at the point of maximal girth with the subject standing in a relaxed stance and their weight evenly distributed over both feet.

Skinfold thicknesses were measured using Harpenden callipers (John Bull, British Indicators, West Sussex, UK) at the biceps, triceps, subscapular, Iliac crest, supraspinale (suprailiac), abdominal, front thigh and medial calf sites. The biceps and triceps sites were identified as a skinfold parallel to the long axis of the arm located respectively on the most anterior and posterior aspect of the arm in line with the mid-acromiale-radiale level. The subscapular skinfold site is determined by the natural fold lines of the skin located 2cm along a line running obliquely downward from the subscapulare landmark at a 45° angle. The iliac crest skinfold site is raised immediately above the iliocristale, the point on the most lateral aspect of the illiac tubercle on the illiac crest. The supraspinale skinfold runs downwards and anteriorly as defined by the natural fold and is located by the intersection of two lines; the line from the marked illiospinale to the anterior axillary border and a horizontal line at the level of the marked iliocristale.

The abdominal skinfold is a vertical fold taken 5cm to the right hand side of the omphalion (midpoint of the navel). The front thigh skinfold is located at the mid-point of the distance between the inguinal fold and the superior margin of the anterior face of the patella on the midline of the thigh. Subjects were instructed to extend the leg whilst in a sitting position and support the leg by placing their hands under the hamstrings and pulling upwards, this assists in raising the skinfold. The medial calf skinfold is located on the most medial aspect of the calf on the level of the maximal girth, this measure is taken with the subject's right foot placed on a box creating an angle of approximately 90° at the knee.

Somatotype were calculated using the Heath Carter somatotype method . Body mass index (BMI, kg.m-2) was calculated by dividing the body mass in kilograms (kg) by the square of stature (m). Sum of eight skinfolds and sum of six skinfolds (excluding biceps and illiac crest) were calculated according to the method of Norton & Olds (Carter 1980, 2004). Body fat percentage values were calculated using the equation of Yuhasz (1974).

2.2.3 Statistical analsysis

Means and standard deviations were calculated for each of the anthropometric variables. As the ranking data (dependant variable) was at neither the interval or ratio level, Spearman`s rank correlation coefficients were calculated to establish the relationships between the different anthropometric variables and the ranking of the professional surfers. The same analysis was used to determine the relationship between the anthropometric variables and the final British ranking at the end of the season for the junior British surfers. The Hutt et al(2001) rating of surfers was used to quantify each surfer`s surfing skill and was correlated with each surfer`s anthropometric variables by means of the Spearman`s rank correlation coefficient method for the intermediate surfers. In order to determine the relationships between anthropometric variables and surfing ability across all three groups the data set was combined based on ability; with the professional surfers (Hutt rating 8) being ranked in order of their season’s rating, above the top amateur junior surfers (Hutt rating 7) who were also ranked in order according to their season’s ratings The top amateur junior surfers were ranked above the intermediate surfers who were ranked only on their Hutt surfer skill rating. Combining performance ranking with Hutt ratings therefore created 36 levels of ability ranging from level 3 intermediate surfers who were able to successfully ride laterally along the wave and generate speed upon the face of the wave; to the top ranked level 8 professional surfer (who were are all able to consecutively execute advanced manoeuvres). Correlations were weighted so that a positive correlation would indicate an increase in performance with increasing value of the independent variable.

An analysis of covariance (ANCOVA) was used to test for significant ($P < 0.05$ or $P < 0.01$) differences between the surfer groups; junior, professional and intermediate male surfers. Age was considered as a covariate as this factor could possibly confound the relationships between the physiological variables across the groups of surfers that were significantly different in age. A Kolmogorov-Smirnov test was used to test the normality of the data used in ANCOVA. Where the distribution of the data was significantly different to that of a normal distribution a Kruskal-Wallis test was used to identify differences between the groups. All statistical analyses were performed using IBM SPSS statistics V20.

2.3 Results

Table 2.2. Skill and anthropometric variables in professional, national junior and intermediate level surfers (mean ± s).

Measure	Professional (*n*= 17)	Junior (*n*= 16)	Intermediate (*n*= 47)
Body mass (kg)	78.6 ± 7.2 **	63.3 ± 7.2 ††	77.8 ± 9.4
Stature (cm)	177.3 ± 6.3	173.9 ± 5.7	179.9 ± 5.4**
Triceps skinfold (mm)	8.7 ± 4.3	7.7 ± 2.4	8.9 ± 2.9
Subscapular skinfold (mm)	10.9 ± 4.5	8.1 ± 2.6	10.6 ± 4.4
Biceps skinfold (mm)	3.8 ± 1.2	4.7 ± 0.8	5.1 ± 2.5
Iliac Crest skinfold (mm)	14.4 ± 6.8	8.8 ±4.0	13.6 ± 5.6
Supraspinale skinfold (mm)	7.0 ± 3.5	6.8 ± 2.2	10.1 ± 4.6*†
Abdominal skinfold (mm)	14.7 ± 5.2*	10.5 ± 4.4	14.6 ± 6.4**
Front thigh skinfold (mm)	13.3 ± 7.7	11.0 ± 2.9	11.9 ± 3.5
Medial calf skinfold (mm)	9.7 ±5.7	8.2 ± 2.2	8.4 ± 2.3
Relaxed arm girth (cm)	33.4 ± 2.2**	27.7 ± 4.2†	31.9 ± 2.4**
Flexed arm girth (cm)	34.0 ± 2.4	30.5 ± 2.5	34.5 ± 2.5
Waist girth (cm)	83.1 ± 3.9	73.0 ± 3.3	81.2 ± 5.7
Gluteal girth (cm)	101.0 ± 4.6	85.0 ± 9.6	98.6 ± 5.4
Calf girth (cm)	37.1 ± 1.3**	34.1 ± 2.6††	36.8 ± 2.6**
Humerus breadth (cm)	6.9 ± 0.4	6.7 ± 0.5	6.4 ± 0.5††
Femur breadth (cm)	9.6 ± 0.4	9.2 ± 0.4	9.0 ± 0.7††
Endomorphy	2.5 ± 1.1	2.2 ± 0.7	2.8 ± 1.0
Mesomorphy	5.0 ± 1.0	3.7 ± 0.9††	3.6 ± 0.9††
Ectomorphy	1.0 ± 1.1	3.2 ± 1.4	2.4 ± 1.1††
Body mass index (BMI)(kg.m^{-2})	25.0 ± 1.6**	20.9 ± 1.9††	23.9 ± 2.5**
Sum of 6 skinfolds (mm)	64.3 ± 28.1	50.7 ± 14.3	64.4 ± 20.2
Body fat percentage (%)	11.3 ± 4.2*	8.4 ± 2.4 †	10.9 ± 21.5*

*****significantly different to junior surfers P < 0.05, **significantly different to junior surfers P < 0.01, † significantly different to professional surfers P < 0.05, †† significantly different to professional surfers P < 0.01.

Significant differences (P <0.05) were observed between the professional and junior surfers for body mass, illiac crest skinfold, abdominal skinfold, relaxed arm girth, calf girth, mesomorphy, Ectomorphy, BMI and body fat percentage. Significant differences (ANCOVA, P < 0.05) were also observed between junior and intermediate surfers for stature, iliac crest skinfold, supraspinale skinfold, abdominal skinfold, calf girth, endomorphy, ectomorphy, BMI, sum of six skinfolds and body fat percentage. Further significant differences (P < 0.05) were found between the professional and intermediate surfers for illac crest skinfold, supraspinale skinfold, humerus breadth, femur breadth, mesomorphy and ectomorphy. The Kolomogorov-Smirnov analysis identified that the data for bodymass, triceps skinfold, subscapular skinfold, biceps skinfold, iliac crest skinfold, supraspinale skinfold, abdominal skinfold, front thigh skinfold, medial calf skinfold, relaxed arm girth, flexed arm girth, waist girth, gluteal girth, humerous breadth, endomorphy, ectomorphy, body mass index, sum of six skinfolds and body fat percentage were significantly different to a normal distribution (P < 0.05). Using a Kruskal-Wallis test significant differences were found for the sum of six skinfolds with the junior surfers being significantly lower than the intermediate surfers (P < 0.05). No other differences were apparent between the results of analysis using ANCOVA or Kruskal-Wallis.

Table 2.3 Surfer's Spearman`s rank correlations (r_s) between anthropometric indices and performance ranking.

	Professional (n = 17)	Junior (n = 16)	Intermediate (n = 47)	Combined (n = 80)
Endomorphy	- 0.199	0.357	-0.399**	- 0.366**
Mesomorphy	- 0.094	-0.061	- 0.028	0.442**
Ectomorphy	- 0.641	- 0.018	0.239	- 0.204
Body mass Index (BMI) ($kg.m^{-2}$)	- 0.015	- 0.011	- 0.252	- 0.088
Sum of 6 skinfolds (mm)	- 0.270	0.227	- 0.341*	- 0.274*
Body fat %	- 0.187	0.314	- 0.380**	- 0.268*

*correlation significant at $P < 0.05$, **correlation significant at $P < 0.01$

Professional surfers anthropometric measures were correlated with competition ranking, junior surfers with national ranking, intermediate surfers with Hutt rating, combined data set related to sample ranking.

Significant correlations ($P < 0.05$) were found within the intermediate group between Hutt scale ranking and Endomorphy, sum of six skinfolds and body fat percentage.

Significant correlations were found for the combined data (across all groups) between overall ranking and endomorphy, mesomorphy, ectomorphy and body fat percentage.

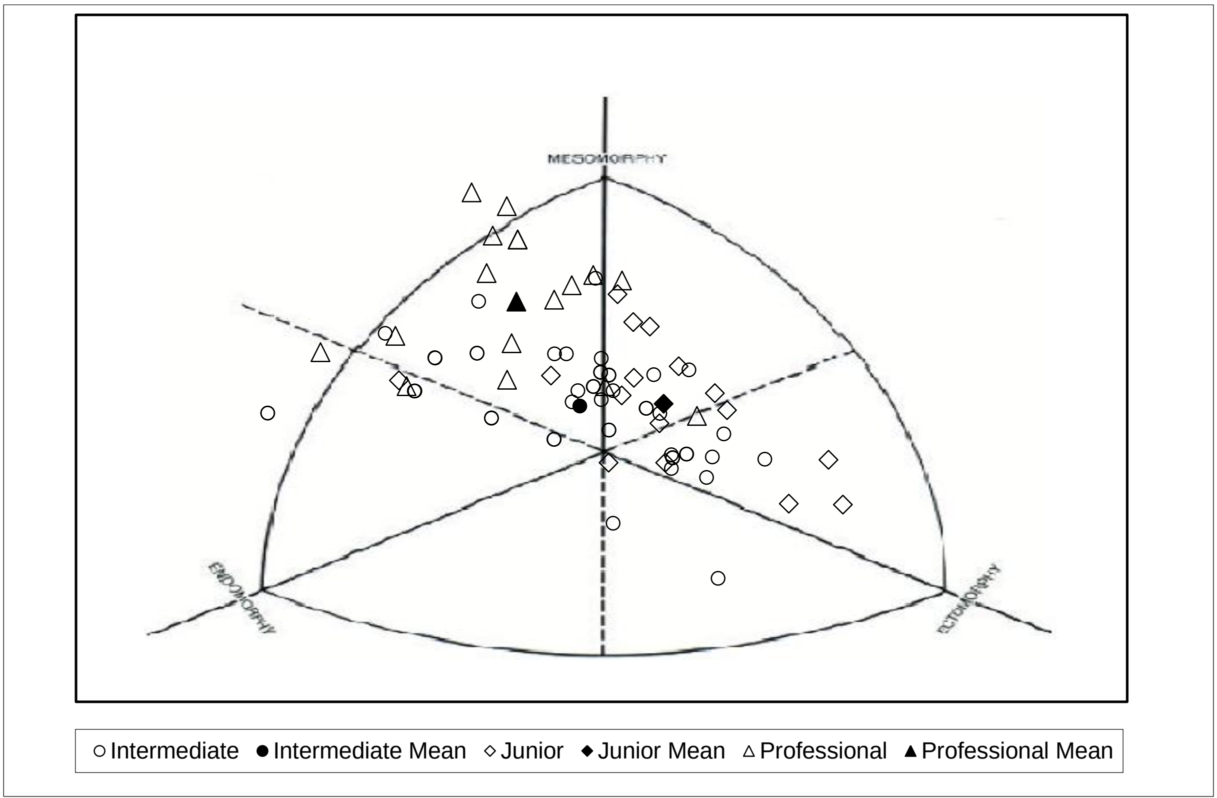

Figure 2.3 Somatotype distributions of the male surfers.

Intermediate male surfers (n = 47), mean somatotype = 2.8 - 3.6 – 2.4; junior surfers (n = 16), mean somatotype = 2.2 - 3.7 - 3.2; Professional surfers (n = 17), mean somatotype = 2.5 - 5.0 - 1.0

2.4 Discussion

The purpose of this study was to evaluate the anthropometric profiles of surfers and to identify any anthropometrical factors which might predict performance and ability in surfing. The key findings of this study suggest that there were significant differences between the individual groups of surfers for various anthropometric measures and that each group can be described with a specific somatotype; professional surfers 2.5 – 5.0 – 1.0, junior surfers 2.2 – 3.7 – 3.2, intermediate surfers 2.8 -3.6 – 2.4. Furthermore, it has been identified that mesomorphy is positively correlated with level of ability (r_s = 0.442, P<0.01) whereas endomorphy, sum of six skinfolds and body fat percentage are inversely related to level of ability in surfing (r_s = - 0.366, P<0.01, r_s = -0.274, P<0.01 and

The measures of stature (177.3 ± 7.2 cm) and body mass (78.6 ± 7.2 kg) suggest that changes might have occurred with male surfers since Lowdon`s (1980) study, with the current professional surfers being both taller and heavier than Lowdon`s (1980) participants who were reported as 173.63 ± 5.87cm tall and 67.99 ± 7.17 kg in mass . Body mass values for the professional surfers derived from the present study are also higher than those reported for European Level Surfers (ELS) by Mendez-Villanueva et al. (2005) (71.1 ± 2.6 kg). The body fat percentage values of the professional surfers in the current study (11.3 ± 4.2%) are similar to those presented by Lowdon and Pateman (1980) for international surfers (9.1-13%). Sum of six skinfolds values (64.3 ± 28.1 mm) were much higher for the professional surfers than those reported for ELS (47.6 ± 7.3 mm)by Mendez-Villanueva et al.

(2005). Notably, the mean value for flexed arm girth among the professional surfers in this study was higher than those presented by Lowdon (1980) .

Surfing performance has been found to be highly variable in nature (Mendez-Villanueva et al. 2010) due largely to unstable environmental conditions such as wave size, wind conditions and tide that will vary from competition to competition and heat to heat; indeed these factors will vary over the course of a single heat resulting in inconsistent surfing performance rankings from a single event. These environmental factors coupled with subjective surfing performance assessment of what is a strongly skill focussed sport make it difficult to identify with any confidence and consistency the association between physiological factors and performance from a single event. However, season`s rankings have the advantage of averaging out inconsistencies from event to event, with the most consistent surfers in terms of high ranking in single events securing a higher season`s ranking.

Lowdon (1980) was unable to find any significant differences in 1978 the anthropometric features between the top and bottom rankings surfers in the Bells Beach Surfing Championships. Similarly the results for the surfers in the current study produced no statistically significant correlations ($P > 0.05$) between the anthropometric variables and the rank of the surfers within the group. Suggesting that within this cohort body composition is not a valid predictor of performance.

When the anthropometric data for junior surfers were correlated to their current Great Britain national points standing at the close of the 2008 season; an interesting finding emerged. Insignificant but positive correlations were found between ranking and endomorphy (r = 0.357, P >0.05), sum of six skinfolds (r = 0.227, P >0.05) and body fat percentage (r = 0.314, P >0.05) which might suggest that higher levels of adiposity are associated with better surfing performances among junior surfers. At first, this result was surprising, but in view of the homogeneity of the national junior surfer group, it is not. The levels of body fat percentage are relatively low and do not vary greatly. Both Felder et al(1998) and Lowdon (1980) also suggested that surfers might benefit from a comparatively higher level of body fat due to the insulation needed in the cold water, although this advantage will be negated by the use of wetsuits. Furthermore Felder et al(1998) noted that surfers generally make use of poor nutritional strategies which might lead to a state of energy deficit during periods of increased surfing frequency and extended surfing sessions (up to 4-5 hours) (Mendez-Villanueva and Bishop 2005). In these periods fat deposits might act as a useful source of energy (Ranallo and Rhodes 1998). Therefore, surfers in the junior group who are at the lower end of the body fat percentage range (6.6%-10.8%) might suffer reduced ability to perform activity and manoeuvres due to limited availability of fat energy sources during extensive surfing sessions. Surfers generally do not seek nourishment or fluid replenishment during a surfing session and free fatty acids might compensate for lower glycogen levels towards the end of the session (de Bilderling et al. 2005). However Meir et al(1991) suggests that the average heart rate during surfing was 75% of the maximum achieved in laboratory tests; therefore carbohydrate should act as the principle substrate for metabolism (Venables et al. 2004). The junior surfers exhibited lower levels of body fat (8.4 ± 2.4 %) than comparative groups of junior volleyball players (11.5 -12.9 %) (Duncan et al. 2006) and active children and youths (11.3 ± 6.6 %) (Watts et al. 2003) but the surfer`s values were higher than junior competitive sport rock-climbers (4.4 ± 2.2 %) (Watts et al. 2003). The sum of six skinfold values for the junior national level surfers (50.7 ± 14.3mm) were similar to the values reported by Mendez-Villanueva et al(2005) for European Level Surfers (46.5 ± 15.4 mm) . It is accepted that the junior surfers in the current study are considerably younger (15.61 ± 1.06 years) than the participants of Mendez-Villanueva et al(2005) (26 ± 3.2 years) but to date there exists no body composition data for comparatively aged surfers and it is notable to see similar values within the competitive surfers regardless of age.

The range of ability in the group of intermediate surfers ranged from level 3 - surfers able to ride laterally along the wave face with the ability to generate speed by 'pumping' on the wave face; to level 6 – surfers who are able to execute standard manoeuvres such as bottom turns, top turns and cut-backs consecutively and occasionally perform advanced manoeuvres such as 'floaters' and barrel riding. When analysing the intermediate surfers, Spearman`s rank correlations were performed between the calculated anthropometric indices and the rating of surfer skill. Significant relationships were found between ability and endomorphy (r_s = -0.399, P <0.01), sum of six skinfolds (r_s = -0.341, P <0.05) and body fat percentage (r_s = -0.380, P <0.05). These results suggest that lower levels of adiposity are related to higher surfing ability levels among the intermediate group of surfers. This group displayed the highest variability for body fat percentage when compared to the other groups which might be related to the variability in ability.

An analysis of covariance (ANCOVA) was used to compare the anthropometric results between the different groups of surfers with age as a covariate. Significant differences of physical measures between the groups are likely to relate to maturational differences such as the variables of body mass, stature, bicep girth, calf girth and bone breadths but the mesomorphy score for the professional surfers was significantly higher than the values reported for the intermediate surfers suggesting this might be related to performance. There might be some maturational effects within the data with the relatively lower levels of body fat percentage in the junior group perhaps being representative of adipose variations around the time of growth spurts (Norton and Olds 2004). The significant differences in mesomorphy between male groups did not follow the pattern that would be expected of a maturational effect as the youngest group (the juniors) had the second highest mesomorphy scores of the three groups and there was no significant correlation between age and mesomorphy (Bale et al. 1992).

The data from all three groups were combined and the calculated anthropometric variables were correlated with the surfer skill rating and individual rank within the groups (Hutt et al. 2001). Significant correlations with rank within the sample were found for endomorphy (r = -0.366, P = 0.01), mesomorphy (r = 0.442, P = 0.01), sum of six skinfolds (r = -0.274, P = 0.05) and body fat percentage (r = -0.268, P = 0.0). These data suggest that higher levels of muscularity and lower levels of adiposity are associated with improvement in surfing skill along the continuum of ability from intermediate to professional in surfers. In considering maturational effects the correlations between age and skill rating (r = -0.04, $P > 0.05$) and age with group (r = -0.102, $P > 0.05$) were found to be insignificant. However a significant relationship was found between age and overall combined ranking (r = 0.299, $P < 0.05$). This result is interesting as all of the junior surfers were ranked above all of the older intermediate surfers and it might be that this is an artefact induced by the greater mean age of the professional surfers (34.2 ± 3.81 years) who took part in this study. This is in agreement with the view of Mendez Villanueva & Bishop (2005) who found professional surfers to be consistently over the age of 25, perhaps as a result of the time taken to master the skills required and the strategy of competition with potential financial rewards delaying retirement. Indeed Kelly Slater the current 11 times world surfing champion is one of the oldest (39 years of age) and the highest earning surfers (over $3 million) on the professional tour (ASP, 2011).

2.5 Conclusions

It appears that different factors might be influential, dependent on the level of participation. Within the ranks of male professional surfers it would seem those exhibiting optimised muscularity whilst maintaining a relative low BMI are favoured. The results of the study also indicate that male Junior National surfers need to be mindful of maintaining appropriate levels of body fat but not allowing these to fall too low; and intermediate level surfers need to manage their weight to maintain relatively low levels of body fat to underpin improvement in performance. Overall the study concludes that levels of adiposity and muscularity are factors that might influence surfing ability and the progression from intermediate to professional level surfing performance.

The results for female surfers currently offer little insight into the relationships between the anthropometric profiles of surfers and their levels of ability. This is most likely to be a result of the low number of participants in this cohort and further research is required in the area.

The practical implications of this study are that a mesomorphic somatotype / upper body muscularity should be encouraged to allow surfers to achieve high levels of performance. However when working with junior athletes coaches should consider maintaining sufficient levels of body fat as comparatively low levels of body fat do not necessarily relate to high levels of performance in this cohort. Conversely intermediate and professional surfers need to manage their weight to maintain relatively low levels of adipose tissue.

2.6 Future research possibilities

The lack of data relating to the female surfers has led to little insight regarding this cohort. It is suggested that future research can be directed towards creating a representative data set for this population.

The relationships between the adiposity of the junior surfers and their level of ability suggest that it might be worthwhile investigating whether there is a relationship between adiposity and fat metabolism during exercise for these participants to determine whether the relationship between adiposity and performance is due to metabolic adaptations and substrate availability (Wade et al. 1990) or whether this is due to the insulator effect of the adipose tissue facilitating extended surfing sessions (Lowdon 1980, Felder et al. 1998).

2.7 Acknowledgements

The authors wish to thank the British Surfing Association (BSA) and the British Professional Surfing Association (BPSA) for facilitating access to participants.

Chapter 3.0 Physiological parameters and their relationship to ranking in male high performance junior surfers

Part of this chapter formed the basis of the oral presentation “Physiological indices of fitness and prediction of competitive national rank in high performance junior British surfers” presented at The European College of Sports Science (ECSS) 13th Annual congress, Estoril, Portugal, July, 2008. An abstract of which was published in the “Book of abstracts of the 13th Annual Congress of the European Journal of Sports Science – 9 -12 July, Estoril – Portugal. Eds Cabri, J., Alves, F., Araujo, D., Barrerios, J., Diniz, J., Velso, A. A copy of which can be found in Appendix 3 and 3.1. The presentation was based on preliminary analysis of a partial version of the data set and the findings presented in this thesis represent an evolution of the study.

3.1 Background to the study

“In sport, as in other domains such as science, music and the arts, the attainment of excellence is the primary goal of many individuals. Spectators marvel at expert performance, coaches endeavour to nurture their protégés towards new heights of achievement and athletes aspire to ‘greatness’. As a consequence the study of expertise in sport, together with the identification and development of future performers, is a respected area within the sport sciences.” Williams and Reilly (2000) (p657).

The statement above is true within the sport of surfing and certainly here within the United Kingdom the national governing body for surfing – Surfing Great Britiain includes the following statement within its core aims “Implementing performance development strategies with the view to producing a British world title contender within the next 10 years" (SurfingGB 2013. About us) . The world class talent programme is an initiative of UK sport to designed to support the identification and confirmation of athletes who have the potential to progress through the World Class pathway with the help of targeted investment (UK Sport 2013). The talent identification involved in the process is based upon both the art of coaching and scientific knowledge and assessment.

Success at any level within surfing requires high levels of skill execution and technical ability, but it is possible that at the high level of performance physiological attributes might also be important (Mendez-Villanueva and Bishop 2005). Mendez Villanueva et al (2005) and Lowdon & Pateman (1980) outlined some physiological parameters of high performance surfers and it has been found that the aerobic power output and the exercise intensity corresponding to a blood lactate concentration of 4.0 $mMol.L^{-1}$ were significantly correlated with surfing performance (rank) in adult male regional and European standard surfers (r = -0.58, P = 0.03).

To date no information exists relating to junior high performance surfers. However, anthropometric and physiological profiling have been utilised as a method of talent identification in other sports such as volleyball (Peltenburg et al. 1982), squash (Melrose et al. 2007), rock climbing (Watts et al. 2003), Ice Hockey (Sharma et al. 2012), rugby league (Sheppard and Young 2006, Ortega et al. 2011), basketball (Fernandes-Lopez et al. 2012), triathlon (Landers et al. 2000) and synchronised swimming (Sjodin and Jacobs 1981). Identifying talent at an early age can ensure that performers receive specialised coaching and training to accelerate the talent development process (Williams and Reilly 2000). Moreover it has been shown that talent identification programmes are more likely to be successful in sports when the standard and depth of competition are mediocre in comparison to other sports (Hoare 1998); this suggests that talent identification might be useful in British Surfing. Recently the British Junior team competed in the International Surfing Association (ISA) World Surfing Games and were placed as 13th out of 27 countries; which might indicate that British surfing might benefit from a talent identification programme but as yet one is not in place.

To date no literature exists pertaining specifically to talent identification in surfing but there has been work performed in various other sports with Australia leading the field with its National Talent Search Initiative for a range of sports (Hoare 1996). This involves large scale screening of the secondary school student population, with athletes identified based on a model of desirable characteristics that have been identified at a discipline specific level for a variety of sports (Hoare 1998). By far the most researched sport with respect to talent identification across the globe is soccer (football).

Talent identification within soccer is generally based upon three main components – physical predictors, physiological predictors and psychological predictors (Williams and Reilly 2000). The physical predictors relate to anthropometric measurements (e.g. stature, body mass, bone composition, bone diameter, limb girth) with successful young players having similar somatotypes and physiques to older successful performers. Stature is commonly used for prediction and is largely determined by genetics whereas other physical measures are influenced by training and diet (Reilly et al. 2000). Refer to Chapter 2 in this thesis for a wider discussion on anthropometric measures and surfing performance.

3.1.1 Physiological predictors of performance

Within soccer, physiological measures have been used to predict performance in junior players with measures such as $\dot{V}O_{2max}$, anaerobic power, grip and trunk strength, and heart volume (absolute and relative), being related to selection by teams of the top leagues in Europe. Players who did not perform well in the physiological tests did not progress beyond regional leagues (Jankovic et al. 1997). Janssens et al. (1998) showed that performance in short (30 metre) and prolonged 'shuttle' running discriminated between successful and less successful 11-12 year old soccer players. Furthermore a study by Panfil et al. (1997) found that elite 16 year old soccer players performed better in running and jumping tests than their non-elite counterparts. The findings of these studies suggest that physiological measures can be used to predict later success in soccer. It is noted that the physiological superiority of many of the successful players might be due to a more systematic approach to training before their introduction into the specialised under-age squad (Williams and Reilly 2000). It should however be noted that physiological and performance indices can vary throughout the season within Soccer and other seasonal sports (Koutedakis et al. 1993, Metaxas et al. 2006, Magal et al. 2009).

3.1.2 Psychological predictors of performance

Although it is often suggested by coaches and players that talented athletes can be differentiated from less talented on the basis of psychological factors such as personality (Williams and Reilly 2000). However, researchers have not been able to report consistently any personality characteristics or traits that predispose athletes to athletic success (Morris 2000) and it is suggested that researchers and coaches should focus on cognitive factors, sports specific intelligence and decision making processes to differentiate between skilled and less skilled participants (Williams and Davids 1995).

3.1.3 Physiological characteristic of surfers

The first published study to assess the physiological profile of surfers was performed by Lowdon & Pateman (1980). This study assessed male (n = 76, mean age ± s = 22.2 ± 3.2 yrs) and female (n = 14, mean age ± s = 31.6 ± 3.4 yrs) surfers attending the Australian `Bells Surfing Championship`s in 1978. The study involved field assessments of reaction and movement time, balance, body fat percentage, forced vital capacity (FVC) and estimation of $\dot{V}O_{2max}$. Reaction and movement time were assessed using a Lafeyette reaction / movement timer. The test involved independently mounted response keys, 30 cm apart; with one key activating the reaction time. A stimulus (green light) was placed between the keys and subjects were required to depress the reaction key with the index finger of their dominant hand. When the subjects were ready, the stimulus was given (green light) and the subjects were required to abduct their finger from the reaction key and depress the second key. The time between stimulus and abduction of the finger was measured to give reaction time, and movement time was measured as the total time from stimulus to the depressing of the second key minus the reaction time.

Lowdon and Pateman (1980) found no significant differences for reaction time and movement time between male and females surfers. However reaction times for male surfers were significantly faster than a comparative group of Physical Education (PE) students and non PE students; female surfers were also significantly faster than non-PE students. Furthermore, it was found that the movement times of male surfers were significantly faster than PE and non-PE students. Female surfers also possessed significantly faster movement times than PE and non-PE students. This suggests that rapid reaction and movement responses are an important characteristic of competitive surfers. Balance was measured using two methods; a "two foot lengthwise balance – eyes open test" (Lowdon 1980) and a teeter board test (balance board). There were non-significant differences between the male and female surfers.

Lowdon and Pateman (1980) also assessed the lung function of the surfers by comparison of their forced vital capacity (FVC) and forced expiratory volume in one second (FEV1). These were also compared to the values predicted for age and height. The male surfers achieved values which were 111.5 ± 12.0 % percent higher than predicted and the females achieved values which were 120.2 ± 14.1% above predicted values, suggesting that surfers possess greater lung function capacities than average when compared to the reference values of non-PE students. $\dot{V}O_{2max}$ was estimated using a bicycle ergometer following the procedures of (Astrand and Rodahl 1977). The male surfers achieved $\dot{V}O_{2max}$ values of 70.2 ± 4.73 $ml.kg^{-1}.min^{-1}$, with female surfers achieving $\dot{V}O_{2max}$ values of 62.2 ± 3.72 ml.kg-1.min-1. These values are somewhat high in comparison to other sports (Mc Ardle et al. 2007).

Lowdon (1989) further investigated the $\dot{V}O_{2max}$ of surfers in another study which studied the various methods of testing the aerobic fitness of surfers. The study involved the assessment of $\dot{V}O_{2max}$ via:

Treadmill running (TR)

Prone hand-cranking (HC)

Tethered board paddling (BP).

This was performed on a group of University of California team surfers (n =12, age = 20.7 ± 1.2 yrs, stature = 177.7 ± 7.2 cm, body mass = 70.5 ± 5.1 Kg). The study found that treadmill running elicited the highest $\dot{V}O_{2max}$ of 56.3 ± 3.9 $ml.kg^{-1}.min^{-1}$, with Board paddling and hand cranking eliciting $\dot{V}O_{2max}$ values of 40.4 ± 2.9 $ml.kg^{-1}.min^{-1}$ and 41.6 ± 4.0 $ml.kg^{-1}.min^{-1}$ respectively. Lowden (1989) stated that although the $\dot{V}O_{2max}$ values for the treadmill running were indeed the highest for the methods used, this method was perhaps inappropriate as the movements involved did not replicate those used during surfing. Furthermore he found that subjects reported lower ratings of perceived exertion (RPE) prior to exhaustion during the tethered board paddling and prone arm cranking than during treadmill running, suggesting that the subjects were more comfortable with this method of testing. The tests of tethered board paddling and hand cranking produced similar physiological results and thus it was concluded that prone hand cranking provided a valid substitute to the more complex laboratory requirements of tethered board paddling for the assessment of the aerobic fitness of surfers.

The results for $\dot{V}O_{2max}$ reported by Meir et al (1991) using a swim bench based protocol were greater than the results derived from hand-cranking and tethered board paddling by Lowdon (1989). However the results produced by Lowdon's (1989) Treadmill protocol were comparable to Meir et al`s (1991) swim bench protocol. Thus far no study has achieved $\dot{V}O_{2max}$ values in the order of those reported by Lowdon (1980), possibly due to the fact that a predictive method of assessment (Astrand Rhyming nomogram) was used rather than direct measurement.

Using an adapted wind braked kayak ergometer Mendez-Villanueva et al. (2005) tested the aerobic fitness of two groups of male competitive surfers. The surfers were either European Level Surfers (ELS) (n = 7, age = 25.6 ± 3.4 yrs, body mass = 67.0 ± 4.3 kg, stature = 172.1 ± 4.9 kg) or Regional Level Standard (RLS) (n = 6, age = 26.5 ± 3.6 yrs, body mass = 71.1 ± 2.6 kg, stature = 174.9 ± 4.7 kg). The protocol consisted of a continuous incremental exercise test with four, three minute stages at power outputs of 30, 45, 60 and 75 watts. This was then followed by a maximal effort to volitional exhaustion. $\dot{V}O_{2max}$ was taken as the highest $\dot{V}O_2$ measured during 30 seconds and Wpeak was taken as the highest power output achieved ear lobe blood samples were taken and measured at the end of each stage for the determination of blood lactate concentration. The results showed that the only significant difference in physiological parameters between ELS and RLS was percentage $\dot{V}O_2$ at which 4.mMol.L^{-1} (LT4) occurred. With ELS achieving LT4 at 95.2 ± 3.4 % of $\dot{V}O_{2peak}$ compared to RLS where LT4 occurred at 88.9 ± 5.0 % of

$\dot{V}O_{2peak}$. Further analysis found that the power output associated with LT4 was significantly correlated to surfing performance as measured through placement in competition. The use of the power output associated with 4.0 mMol.L^{-1} blood lactate concentration as an measure of training status was proposed by Mader et al. (1976). According to Jones and Doust (2001) this might have been based upon the suggestion that muscle lactate transporters become saturated at approximately 4.0 mMol.L^{-1} muscle lactate. Heck et al. (1985) observed that endurance trained athletes could tolerate workloads that elicited 4 mMol.L^{-1} of blood lactate for long periods of time and that higher workloads normally resulted in a continual increase in lactate concentration. The 4.0 mMol.L^{-1} reference point was termed as the 'onset of blood lactate accumulation' (OBLA) by Sjodin and Jacobs (1981).

Measurement of blood lactate as an indicator of training status is often routine in many sports science laboratories. The power output associated with various concentrations of lactate in blood is used to predict performance in many sports (Jones & Doust, 2001). Fernandes-Lopez et al. (2012) measured the power output associated with the lactate threshold, as described as the point where blood lactate concentration increased by 1mMol.L^{-1} above baseline values (Coyle et al. 1991) and OBLA (Sjodin and Jacobs 1981) in professional junior Basque surfers and found that the relative power output at lactate threshold was significantly correlated with ranking position (lactate threshold r = -0.60 P = 0.065, OBLA r = -0.79, P = 0.006).

Mendez-Villanueva and Bishop (2005) performed a review of the literature comparing the $\dot{V}O_{2peak}$ of male surfers achieved through upper body exercise (Lowdon and Pateman 1980, Lowdon 1983, Meir et al. 1991, Mendez-Villanueva et al. 2005) and calculated the average $\dot{V}O_{2peak}$ of surfers to be 46.84 ml.Kg^{-1}.min^{-1} or 3.3L.min^{-1} . Farley et al. (2011) investigated the relationship between aerobic capacity, anaerobic power and season rank in national level surfers. $\dot{V}O_{2peak}$ was assessed using an incremental paddling protocol that was performed on a modified kayak ergometer (Dansprint, ApS, Denmark). Anaerobic power was measured by performing a maximum effort for 10 seconds and recording both peak and average power. The $\dot{V}O_{2peak}$ values recorded through the study were 44.0 ± 8.3 ml.kg^{-1}.min^{-1}; thus very similar to those reported in an earlier study by Mendez-Villanueva and Bishop (2005). The peak anaerobic power was 205.0 ± 54.2 watts. The study found a non-significant relationship between end of season ranking and $\dot{V}O_{2peak}$. However significant relationships were found between peak anaerobic power (r = -0.55, P = 0.05), mean anaerobic power (r = 0.57, P = 0.01), relative power (W.Kg^{-1}) (r =0.50, P =0.05) and end of season ranking. Farley et al (2011) speculate that higher anaerobic power outputs could allow the higher ranked surfers to catch more waves than their lower ranked counterparts. This notion is both possible and logical; however it also possible that high anaerobic capacity might also reflect the surfer's ability to perform high scoring powerful manoeuvres during the during wave riding; this could be assessed by comparing anaerobic power to the number of waves caught in a session or the manoeuvres performed on the wave.

Loveless and Minahan (2010) compared the $\dot{V}O_{2peak}$ of junior recreational (mean age = 18.0 ± 2.0 yrs) and competitive surfers (mean age = 18.0 ± 2.0 yrs). The $\dot{V}O_{2peak}$ was assessed through an incremental protocol using a swim bench (Vasa swim ergometer, Vasa inc, Essex, USA). Efficiency was assessed by calculating the oxygen uptake to power output relationship during the four stages of the incremental protocol. The $\dot{V}O_{2peak}$ values for the recreational (2.5 ± 0.5 L.min^{-1}) and the competitive (2.7 ± 0.35 L.min^{-1}) were not significantly different to each other and were lower than the mean of value (3.3 L.min^{-1}) reported for surfers by Mendez Villanueva and Bishop (2005) using similar protocols. Loveless and Minahan (2010) found no significant differences in the power output associated with $\dot{V}O_{2peak}$ between the two groups which is in contrast with Mendez Villanueva et al (2005) who found higher peak power values associated with European Level Surfers when compared to Regional Level Surfers. Loveless and Minahan (2010) argue that the differences between the findings of their study and those in the Mendez Villanueva et al (2005) study are due to maturational differences between the participants of the two studies. Loveless and Minahan (2010) suggest that it cannot be assumed that all of their participants were post-pubescent and that Malina et al. (2004) suggest that peak power output can increase dramatically during puberty. However, Baxter-Jones et al. (1993) also argue that $\dot{V}O_{2peak}$ increases dramatically during puberty and as such it likely that if maturational factors had affected the power associated with $\dot{V}O_{2peak}$ then it would have also affected the comparison of the two studies in terms of $\dot{V}O_{2peak}$. It should also be considered that the mean age of the participants in the Loveless and Minahan (2010) study was 18.0 yrs and it is reported that most boys complete puberty between the ages of 13.7 and 17.9 yrs (Lee 1980) thus it is possible that other factors such as ability are responsible for the variation in the findings.

Loveless and Minahan (2010) found that the competitive surfers exhibited lower levels of blood lactate during the exercise tests. When considering the results of the Mendez-Villanueva et al (2005) study it is possible that blood lactate and the power associated with LT4 is an important parameter when assessing the fitness of surfers and might be a predictor of competitive performance in adult high performance surfers.

Lowdon (1980) suggested that power, agility and balance were possibly related to performance in surfers. This is supported by the research of Eurich et al (2010) who suggested that upper body power was related to the ability to perform the pop-up when surfing. It was also suggested that by improving the pop-up action, a surfer can maximise his scoring potential by starting to surf a wave earlier and thus increasing their riding time. Eurich et al (2010) support this notion by referring to a report on surf judging by Lowden (1996), who stated that the length of ride was the main determining factor for the scores awarded by judges. However, the Lowdon (1996) report was based on the judging criteria at the time which included references to points being awarded for riding "the biggest and best waves, for the longest functional distance" (ASP 1987, P58). By the time of the Eurich et al (2010) study the criteria had been changed and any reference to length of ride removed (ASP 2013). Thus it is unlikely that the influence of upper body power on the ability to pop-up had any impact on scoring through increasing length of ride. The ability to pop-up might none the less influence the consistency with which surfers catch waves and therefore the number of rides they achieve. Furthermore the length of ride achieved is more likely to be determined by positioning in the line-up rather than the speed of their pop-up, assuming that the surfer is adept at the pop-up manoeuvre. The pop-up manoeuvre itself (on water) can be also be considered in terms of agility as well as explosive strength. Sheppard and Young (2006, P930) define agility as relating to tasks that must involve:

"The initiation of body movement, change in direction or rapid acceleration or deceleration.

Whole body movement.

Involves considerable uncertainty, whether spatial or temporal.

Open skills only.

Involves a physical and cognitive component, such as recognition of a stimulus, reaction or execution of a physical response."

All of the above factors are relevant to the performance of a pop-up during surfing.

Eurich et al (2010) measured upper body power using a force plate and a velocity transducer whilst performing a pop-up movement in the laboratory. The force plate and the velocity transducer (connected to a power rack) are generally static items of equipment that are not easily used in the field. The medicine ball chest throw has been found to be a valid and reliable measure of explosive power (Stockbrugger and Haennel 2001, Stockbrugger and Haennel 2003). The test is portable and easy to administer making it useful for field testing of upper body power.

Lowdon (1980) identified that agility is an important aspect of fitness within surfing and this should be considered along with upper body power in relation to the pop-up phase of surfing. The pop-up is mechanically similar to the Burpee jump (Burpee 1940) or squat thrust jump. The phases of the pop-up are as follows:

Surfer lies in the prone position with their hands on their board below their shoulders.

The surfer performs a “push-up” straightening their arms and arching their back.

The surfer thrusts their hips forward and stands. The hips should twist so that both feet land on the board simultaneously approximately shoulder width part; along the line of the stringer, knees should be flexed and arms used for balance.

Lower body explosive power might be important during surfing as force development of the lower body has been suggested to be a factor that might affect the wave riding aspect of surfing (Mendez-Villanueva and Bishop 2005). Lower body strength and power can be measured in a number of ways such as isokinetic dynamometry, cable dynamometry and jumping tests. Jump tests have been found to offer a valuable index of leg muscular power in both trained and untrained participants (Bosco and Komi 1979, Markovic et al. 2004). Several methods exist to measure explosive power through vertical jumping with the measurement of ground reaction force using a laboratory force plate being considered the “gold standard” technique (Hatze 1998, Vanrenterghem et al. 2001). However there are a number of methods that employ assessment of the participant`s ability to jump vertically as an index of lower body power. This can be assessed relatively simply performing a Sergeant Jump Test (Markovic et al. 2004) or a by predicting the jump height through measurement of flight time using a contact mat or by measuring using a video method (Dias et al. 2011). Belt mats measure jump height by attaching a belt worn around the participant`s waist to a mat on the floor; when the participant jumps a tape or chord is pulled through the reader on the belt until the jumper reaches the apex of their jump. The height jumped can then be recorded from the reader on the belt. Belt mats have been found to be highly valid when compared to force plate analysis providing results within 2% of the criterion method thus suggesting that they are a relatively cheap, reliable portable method of assessing vertical jump height (Ortega et al. 2008, Buckthorpe et al. 2012). Horizontal jump distance has also been found to be a valid and reliable measure of lower body power (Ortega et al. 2008) and the use of the standing long (broad) jump is commonplace.

Both upper body and lower body strength have been found to be related to hand flexor strength which can be assessed using relatively inexpensive, and easy to use hand grip dynamometers (Richards and Palmiter-Thomas 1996, Cohen et al. 2010). Hand grip dynamometry has been found to be both a valid and reliable method of assessing strength (Hager-Ross and Rosblad 2002, Milliken et al. 2008, Ortega et al. 2008, Castro-Piñero et al. 2010) and an indicator of muscle mass and bone mineral density (Chan et al. 2008). Furthermore hand grip strength has been found to correlate significantly with performance in a number of sports found to be significantly related to performance in various sports such as swimming (Geladas et al. 2005, Zampagni et al. 2008, Garrido et al. 2012) and rock-climbing (when expressed relative to body mass) (Giles et al. 2006).

Lowdon (1980) and Mendez Villanueva and Bishop (2005) both suggest that balance is highly important for surfing performance; although Lowdon (1980) found no significant differences between surfers and non-surfers. It is logical to expect balance to play an important role in surfing however variability in the results of static and dynamic balance tests might disguise any relationship with performance. Furthermore, Lowdon (1980) suggests that balance skills are highly specific and thus it is important to use tests that are appropriate for the skills involved in the sport. Thus far no surfing specific balance test exists but field assessments of balance have been performed in a number of sports and activities, with the standing stork test being a popular method for assessing static balance in gymnastics (Peltenburg et al. 1982) and has been used in the assessment of static balance in other sports such as volley ball (Melrose et al. 2007). Dynamic balance can be measured using a simple “wobble board” test whereby the time that the board is in balance is measured (Sharma et al. 2012). The multiaxial movement of the wobble board would be intuitively similar to that of a surfboard and therefore might provide a valid measure of dynamic balance of surfers.

The aim of this chapter was to identify whether physiological parameters measured through field assessments of strength, power, balance, flexibility agility and the results of an incremental exercise test with measurements of $\dot{V}O_{2peak}$ and blood lactate concentration are related to ranking in a sample of male high performance junior surfers.

3.2 Methodology

3.2.1 Participants

Following institutional ethical approval (Appendix 1.1) and the completion of parental informed consent (children giving assent) (Appendix 1.2) 18 elite male (mean age =

15.4 ± 1.4 years) surfers were recruited from the British Junior Surfing team. The subjects were all highly trained individuals who regularly competed in national and international level surfing competitions but were still of school age.

3.2.2 Procedures

After recording resting heart rate, blood pressure was measured using a mercury sphygmanometer (Accosan, Dekomet, Harlow, UK) and stethoscope (Littman, Classic II S.E., Neuss, Germany). Cut off values for participation in the exercise test were a resting heart rate of 100 bpm or above, diastolic blood pressure of 140 mmHg or above and a diastolic blood pressure of 90 mmHg as these values would indicate mild hypertension (ACSM 2013).

Height and body mass were measured using the methods previously described in section 2.2. Body fat percentage and fat free mass were measured using a bioelectrical impedance analysis device (TBF300 MA, Tanita, Middlesex, UK).

3.2.3 Maximal oxygen uptake

Maximal oxygen uptake ($\dot{V}O_{2\,peak}$) was predicted from a sub-maximal test as institutional ethical protocol prevented maximal effort testing of juniors. The test

Figure 3.1 High performance junior surfer undergoing $\dot{V}O_{2\,peak}$ assessment.

involved paddling on an adapted kayak ergometer (K1, Australian Sports Commission) for 3 minute stages starting at 20 watts and increasing by 10 watts every three minutes (see figure 3.1). A thirty second rest period was included between stages to allow for fingertip capillary blood sampling. Heart rate was monitored throughout the test via a heart rate monitor (Polar S810i, Polar Electro, OY, Finland) and recorded on a second by second basis. The exercise test was stopped for one of the following reasons:

The participant achieves a heart rate of 85% or greater of their age related Maximum Heart Rate.

The participant indicates a rating of perceived exertion (RPE) of 19 or 20 on the Borg (1998) scale.

The participant signals that they wish to stop.

The tester believes the participant to be under unnecessary physical or psychological distress.

The participant stops exercising, under his or her own volition.

The participant is unable to maintain the specified power output.

(BASES 1997).

Gas analysis was obtained via a face mask (Hans Rudolph, inc, USA.) using the Metalyzer 3B (Cortex Biophysik, GmbH, Leipzig, Germany) metabolic system. The system was calibrated every hour using a Hans Rudolph 3 litre calibration syringe for the volume transducer. The gas analysers were calibrated using both ambient air and a calibration gas (O_2 18.23%, CO_2 2.07%). The pressure sensor was calibrated using a digital barometer (Oregon Scientific). These calibrations were performed via a Toshiba laptop (Satelite pro L20, Toshiba Europe, GMBH). Fingertip capillary blood samples were analysed for blood lactate concentration using an YSI2300 stat (Analytical technologies, Farnborough, UK).

Maximum oxygen uptake ($\dot{V}O_{2peak}$) was estimated by extrapolating the heart rate / $\dot{V}O_2$ relationship using the age predicted maximum heart rate. Maximum heart rate was calculated using the equation: 208 – (0.7 x age) (Tanaka et al. 2001). Power at $\dot{V}O_{2peak}$ was estimated by extrapolating the power / heart rate relationship in the same manner.

3.2.4 Lower body explosive power

Lower body explosive power was assessed using a standing long jump using a padded jump mat (Everque, Nottingham, UK) and a vertical jump test using a digital jump meter (Takai electronics, Tokyo, Japan). The subjects were allowed three attempts at each test with the longest and highest jumps recorded. Upper body power was measured using a 2 kg medicine ball (Stockbrugger and Haennel 2001). The ball throw was performed in a seated position using a chest throw technique. Subjects performed three throws with the longest throw being recorded. Grip strength was measured using a digital hand grip dynamometer (Takai electronics, Tokyo, Japan).

3.2.5 Agility and explosive power

Agility and explosive power was measured using a novel "pop-up" test. The test was based upon the same principles as the Burpee test (Mackenzie 2005). This test simulates the "pop-up" movement performed when surfing. The subjects were required to perform as many "pop-ups" as possible in thirty seconds. The subjects were required to be fully in the prone position (see Figure 3.2) and fully in the standing position in each pop-up (see Figure 3.3).

Figure 3.2 prone position.

Figure 3.3 standing position.

3.2.6 Balance

Balance was measured by performing two tests. The first test involved balancing on a wobble board (16" Pro Wobble board, MFT, Nottingham, UK) for as long a time as possible. Subjects were given three attempts with the longest effort being recorded. The timing began when the edge of the wobble board left the floor and was then stopped when the subject lost their balance and the board contacted the floor. The second test of balance was the standing stork (Peltenburg et al. 1982) test . Subjects were permitted three attempts with the longest attempt recorded.

3.2.7 Flexibility

Flexibility was measured using a sit and reach test. This was performed using a sit and reach box (Cranlea & co, Bourneville, UK). Prior to testing the participants were asked to stretch their hamstrings and lower back. The participant removed their shoes and sat with their legs extended and their feet flat against the vertical side of the box. It was ensured that the participant's legs were straight before testing commenced. The participant then outstretched their arms placing one hand on top of the other with their palms facing downward. The participant then forward as far as possible pushing the finger board along the scale of the sit and reach box. The full stretch is held for 2 seconds to prevent the participant from bouncing. The measure is recorded as the distance from the toe line to the extent of the stretch with measurements beyond the toe line being recorded as positive and measurements before the toe line as negative (Ellis et al. 2000)

3.2.8 Statistical analysis

The physiological assessment was performed one month before the completion of the competitive year. Rankings were taken from the national junior rankings at the end of the competitive year. Statistical analyses were performed using IBM SPSS 20. Spearman's rank correlations were computed between the physiological parameters and the end of year national rankings of the surfers. Further analyses were performed through partial correlations between end of year national rankings and the physiological parameters controlling for age.

3.3 Results

The mean values ± standard deviation of each of the physiological parameters are presented in Table 3.1.

Table 3.1 showing physiological parameters of high performance junior surfers.

Measure	**Mean ±SD**
Age (years)	15.6 ± 1.3
Stature (cm)	1.7.± 7.3
Body mass (kg)	64.1± 6.6
Pop-ups in 30 seconds	19 ± 3
Standing long jump (cm)	200.5 ± 54.5
Vertical jump (cm)	55.8 ± 12.2
Medicine ball throw (cm)	606.2 ± 72.2
Grip strength	47.2 ± 10.9
Balance board test (sec)	4.5± 2.0
Standing stork test (sec)	4.3 ± 2.1
Sit and reach test (cm)	32.6 ± 5.44
$\dot{V}O_{2peak}$ ($l.min^{-1}$)	3.1 ± 0.5
$\dot{V}O_{2peak}$ ($ml.kg^{-1}.min^{-1}$)	47.7 ± 7.2
Power output @ $\dot{V}O_{2peak}$ (watts)	97.6 ± 14.1

Spearman's rank correlations revealed that there were significant correlations between national ranking and power @ $\dot{V}O_{2peak}$ (r_s = -0.877, P < 0.01) (figure 3.4); and national ranking and age (r_s = -0.579, P < 0.05). Pearson correlations found that a number of the measured parameters were significantly related to age; stature (r = 0.469, P < 0.05), body mass (r = 0.530, P < 0.05), vertical jump (r = 0.739, P < 0.05) and power @ $\dot{V}O_{2peak}$ (r = 0.542, P < 0.05). Partial correlations were calculated to control for age and a significant relationship was established between national ranking and Power @ $\dot{V}O_{2peak}$ (r_p = -0.879, P < 0.01). Blood lactate samples were only taken from a small number of participants (n = 3) due to reasons of participant compliance, thus these results were disregarded.

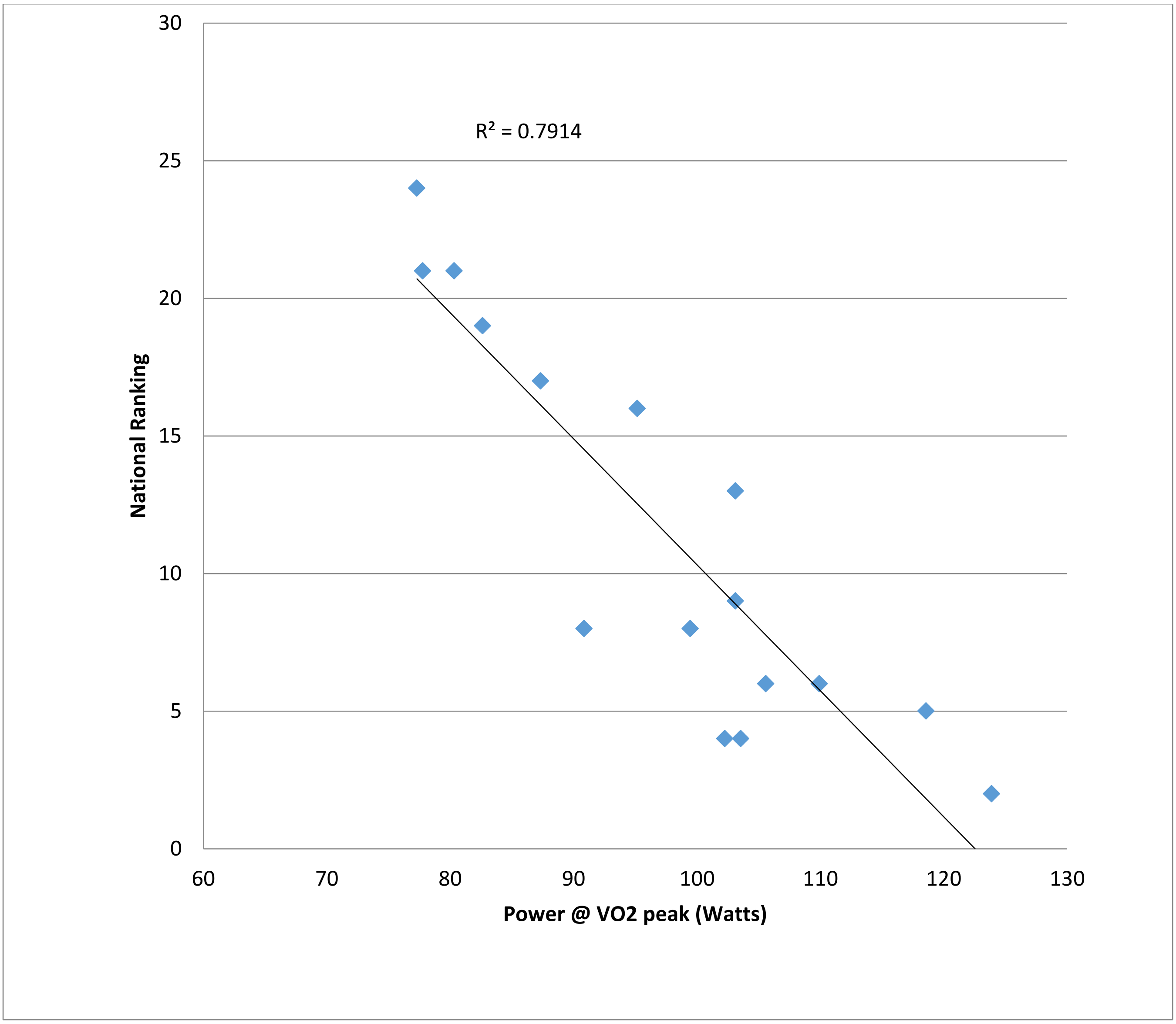

Figure 3.4. The relationship between power @ $\dot{V}O_{2peak}$ and national ranking.

Correlational analyses were also performed between each of the assessment measures and the sample characteristics these are presented in Table 3.2. As age was found to be significantly correlated to a number of variables partial correlations (r_p) were also performed between assessment measures, these are presented in Table 3.3.

Table 3.2 correlations between assessment measures.

	Pop up Test	**Standing long jump**	**Medicine ball throw**	**Balance board test**	**Sit and reach test**	**Standing stork test**	**Vertical jump test**	**Grip strength**	**Absolute $\dot{V}O_{2peak}$**	**Relative $\dot{V}O_{2peak}$**	**Power @ $\dot{V}O_{2peak}$**
Pop up Test	-	0.164	0.018	0.516*	-0.349	0.510*	0.320	0.245	0.363	0.555*	0.260
Standing long jump	0.164	-	0.127	-0.023	0.083	-0.054	0.706*	0.564	0.141	0.130	0.454
Medicine ball throw	0.018	0.127	-	-0.235	0.274	-0.269	0.813**	0.943**	0.456	-0.073	0.232
Balance board test	0.516*	-0.023	-0.235	-	-0.281	0.983**	-0.126	-0.318	0.235	0.485*	0.136
Sit and reach test	-0.349	0.083	0.274	-0.281	-	-0.330	0.497	0.559	0.160	-0.108	0.201
Standing stork test	0.510*	-0.054	-0.269	0.983**	-0.330	-	-0.126	-0.318	0.166	0.422*	0.047
Vertical jump test	0.320	0.706*	0.813**	-0.126	0.497	-0.126	-	0.862*	0.761**	0.228	0.465
Grip strength	0.245	0.564	0.943**	-0.318	0.559	-0.318	0.862	-	0.452**	-0.116	0.377
Absolute $\dot{V}O_{2peak}$	0.363	0.141	0.456	0.235	0.160	0.166	0.761	0.452	-	0.774**	0.531*
Relative $\dot{V}O_{2peak}$	0.555*	0.130	-0.073	0.485*	-0.108	0.422*	0.228*	-0.116	0.774**	-	0.414
Power @ $\dot{V}O_{2peak}$	0.260	0.454	0.232	0.136	0.201	0.047	0.465	0.377	0.531*	0.414	-

*Correlation is significant at *P* < 0.05, **Correlation is significant at *P* <0.01.

Table 3.3 Partial correlations (rp) between assessment measures.

	Pop up Test	Standing long jump	Medicine ball throw	Balance board test	Sit and reach test	Standing stork test	Vertical jump test	Grip strength	Absolute $\dot{V}O_{2peak}$	Relative $\dot{V}O_{2peak}$	Power @ $\dot{V}O_{2peak}$
Pop up Test	-	0.358	-0.089	0.438	-0.887**	0.438	0.039	-0.007	0.210	0.468	0.123**
Standing long jump	0.358	-	0.288	0.246	-0.326	0.246	0.366	0.209	0.237	0.218	-0.473
Medicine ball throw	-0.089	0.288	-	-0.663	0.453	-0.663	0.734*	0.922**	0.341	-0.114	0.049
Balance board test	0.438	0.246	-0.663	-	-0.784*	1.000**	-0.679	-0.786*	-0.081	0.436	-0.002*
Sit and reach test	-0.887**	-0.326	0.453	-0.784*	-	-0.784*	0.322	0.429	-0.059	-0.483*	-0.014
Standing stork test	0.438	0.246	-0.663	1.000**	-0.784*	-	-0.679	-0.786*	-0.081	0.436**	-0.002*
Vertical jump test	0.039	0.366	0.734*	-0.679	0.322	-0.679	-	0.762	0.634*	0.164	-0.087
Grip strength	-0.007	0.209	0.922**	-0.786*	0.429	-0.786*	0.762*	-	0.172**	-0.280*	-0.090
Absolute $\dot{V}O_{2peak}$	0.210	0.237	0.341	-0.081	-0.059	-0.081	0.634	0.172	-	0.827	0.345
Relative $\dot{V}O_{2peak}$	0.468	0.218	-0.114	0.436	-0.483	0.436	0.164	-0.280	0.827	-	0.422
Power @ $\dot{V}O_{2peak}$	0.123	-0.473	0.049	-0.002	-0.014	-0.002	-0.087	-0.090	0.345	0.422	-

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

3.4 Discussion

The aim of this study was to identify whether physiological parameters measured through field assessments of strength, power, balance, flexibility agility and the results of an incremental exercise test with measurements of $\dot{V}O_{2peak}$ and blood lactate concentration are related to ranking in a sample of male high performance junior surfers.

The pop-up test allowed some estimation of the agility levels of the surfers with the surfers performing 19.28 ± 2.91pop-ups in the 30 second period. The results of the pop-up test were not significantly ($P > 0.05$) related to the national ranking of the surfers in this sample and as such it is suggested that it is not a useful marker of rank within a sample of participants who are homogenous in their ability. The results of the pop-up test were significantly correlated to the results of the balance board test ($r = 0.516$, $P < 0.05$) standing stork ($r = 0.510$, $P < 0.05$), and relative $\dot{V}O_{2peak}$ ($r = 0.555$, $P < 0.05$). The relationships between the agility test and the balance tests are surprising as balance is not considered to be an component of agility (Sheppard and Young 2006). The results for the surfers in the standing long jump place the average value for the surfers in the 60-70th centile for 15 year old boys using European standards (Ortega et al. 2011); as such the results for the surfers can be considered above average in this test . However the results for the vertical jump (counter movement jump) exceed the values required for the 100th centile (Ortega et al. 2011) suggesting that the surfers have excellent lower body power in comparison to other European children of the same age. The values for the vertical jump test were found to be significantly correlated with the other assessments of strength and power such as the standing long jump ($r = 0.706$, $P <$

0.05), medicine ball throw (r = 0.813, P < 0.0)and grip strength (r = 0.862, P < 0.05). However, vertical jump height was also related to measures that were indicative of maturity such as age (r = 0.739, $P < 0.05$), stature (r = 0.692, $P < 0.05$) and body mass (r = 0.896, $P < 0.01$). Further analysis using partial correlations correcting for age reduced the number of significant correlations but the medicine ball throw (r_p = 0.734, P < 0.05) and grip strength (r_p = 0.0.762, P < 0.05) were still found to be significantly related to vertical jump height. The inter-relationships between these strength based variables support the use of the vertical jump as a method of assessing strength and power in surfers. There were non-significant relationships between the vertical jump height and the rank of the surfers within the group (r = -0.284, $P > 0.05$) suggesting that this is not an important predictor of performance in this sample. The results for the medicine ball throw were significantly related to other measures of strength and power such as the vertical jump (r = 0.813, $P < 0.01$) and grip strength (r = 0.943, $P < 0.01$). The correlations remained significant when corrected for age through the use of partial correlations however the correlations were slightly reduced with both vertical jump (r = 0.734, P < 0.01) and grip strength (r = 0.922, $P < 0.01$). There were non-significant relationships (r = - 0.253, $P > 0.05$) with ranking and there are no normative data with which to compare these scores to other populations.

The results of the grip strength test rated the surfers in the study above the 80th percentile for European adolescents of similar age (Ortega et al. 2011); and were substantially higher than the values presented for junior swimmers (Geladas et al. 2005) who had mean scores of 34.0 ± 0.6kg. It should be noted that the swimmers were younger (12.8 ± 0.05 years) and lighter (54.1 ± 0.7 kg) than the surfers in the present study and as such these might be maturational differences. Correlational analysis corrected for age revealed that the grip strength was inversely related to the balance measures of the standing stork test (r_p = 0.786, $P < 0.05$) the balance board test (r = 0.786, $P < 0.05$) suggesting that as grip strength increases then balance decreases.

The results of the balance tests correlated very well with each other (r = 0.983, $P <$ 0.01), even when corrected for age (r = 0.784, $P < 0.05$) suggesting that the measures can either be used interchangeably as an indication of balance ability or that the surfers have comparable levels of balance in both static and dynamic scenarios. Lowdon (1980) could find no correlation between the values for static and dynamic balance in his study and concluded that this was due to the tests used not being specific to the balance skills required in surfing. The current data here with the strong correlation between the two measures suggest that the balance board test and the standing stork test are both valid measures of assessing balance in surfers. However it should be noted that there were non-significant relationships between balance and the ranking of the surfers (r = 0.253, $P > 0.05$).

The results for the sit-and-reach test were significantly negatively correlated when corrected for age with the number of pop-ups in 30 seconds (r = -0.887, $P < 0.01$), the results of the balance board test (r = -0.784, $P < 0.05$) and the standing stork test (r = -0.784, $P < 0.05$). The correlations in the results of the pop up tests, jump tests, flexibility, grip strength and balance suggest that there exist consistent relationships between these variables in this sample of surfers. Future studies should investigate whether these variables can predict performance or ability in a range of surfers from novice to advanced.

The absolute ($l.min^{-1}$) and relative ($ml.kg^{-1}.min^{-1}$) maximal oxygen uptake scores were not significantly correlated with national ranking and considerably lower than the value (70.2 $ml.kg^{-1}.min^{-1}$) presented by Lowdon & Pateman (1980). However Lowdon & Pateman`s (1980) values are considerably higher than those reported by other authors in studies relating to surfers, probably due to the nature of the protocol employed. The values in the current study are slightly lower than the values presented by Mendez-Villanueva et al (2005) for European level (adult) surfers (3.3 ± 0.3 $l.min^{-1}$ or 50.0 ± 4.7 $ml.kg^{-1}.min^{-1}$) and the absolute oxygen uptake values for regional level surfers 3.4 ± 0.4 $l.min^{-1}$); but similar to the relative values they presented for regional level surfers (47.9 ± 6.3 $ml.kg^{-1}.min^{-}$1). This comparison suggests that maximal oxygen uptake has little power in differentiating adults and junior surfers. It should be considered that although the participants in the current study were all part of the national squad only a subset of these would go on to compete at an international level and thus be comparable in performance to the European level surfers in Mendez-Villanueva et al`s (2005) study; whereas all of the participants would be competing at a regional level. The differences in the absolute oxygen uptake values between the junior surfers in the current study and the regional level surfers (Mendez-Villanueva et al. 2005) are most likely to be due to the differences in body mass of the two groups who had mean body mass values of 71.1 ± 2.6 kg and 64.1 ± 6.6 kg respectively .

Loveless and Minahan (2010) measured the peak oxygen uptake of competitive and recreational junior surfers. The competitive surfers were all part of the Australian junior squad and as such provide a comparative sample for the participants of the current study with consideration that the Australian surfers averaged 18 ± 1 years for the competitive surfers and 18 ± 2 years for the recreational surfers. The peak values for the participants in the present study demonstrated higher values than both the recreational (2.5 ± 0.5 $l.min^{-1}$) and competitive (2.7 ± 0.4 $l.min^{-1}$) groups of Australian surfers who performed a comparable, incremental, paddling ergometer test.

The values in the current study were also lower than those reported by Meir et al (1991) who found maximal oxygen uptake values to be 3.8 ± 0.8 $l.min^{-1}$ and 54.2 ± 10.2 $ml.kg^{-1}.min^{-1}$ The values for the junior surfers in this study were higher than those reported by Lowdon et al (1989) for collegiate surfers during tethered board paddling (40.4 ± 2.9 $ml.kg^{-1}$.min-1 and 2.9 ± 0.04 $l.min^{-1}$) and during hand cranking (41.6 ± 4.0 $ml.kg^{-1}.min^{-1}$ and 3.0 ± 0.4 $l.min^{-1}$). The values in both the current study and the Lowdon et al (1989) study were lower than those reported by Meir et al (1991) who reported maximal oxygen uptake values of 3.8 ± 0.8 $l.min^{-1}$ and 54.2 ± 10.2 $ml.kg^{-1}.min^{-1}$ for recreational level surfers. It is surprising that recreational surfers achieved higher values than competitive surfers however these differences might be due to differences in the testing protocol or it the low subject numbers (n = 6) in the Meir et al (1991) study and the comparatively large variation in the maximal oxygen uptake values of that study (s = ±10.2 $ml.kg^{-1}.min^{-1}$). Moreover we can assume that competitive surfers focus their sporting activities mainly around surfing whereas recreational surfers might participate in other sports to a greater extent and thus might present fitness profiles influenced by these other sports.

The power output here associated with peak oxygen uptake was lower than the values reported for national level adult surfers (205.0 ± 54.2 watts) (Farley et al. 2011), European (154.7 ± 36.8 watts) and regional level(117.7 ± 27.1 watts) adult surfers (Mendez-Villanueva et al. 2005), junior recreational (199 ± 24.0 w) and junior competitive surfers (199.0 ± 45.0 w) (Loveless and Minahan 2010). The variation in the peak power outputs described by the studies is most likely to represent the difference in ergometry and testing protocol used in each study rather than biological differences in the power outputs of the surfers. The power output associated with maximal oxygen uptake was the only variable in this study to correlate significantly with the national ranking of the surfers. A similar relationship was found by Mendez-Villanueva et al. (2005) between the national ranking and power output associated with peak oxygen uptake in European level surfers; thus suggesting that the power output associated with peak oxygen uptake is an important predictor of ability in competitive surfers.

3.5 Conclusions

This study suggests that UK junior surfers are above average for grip strength when compared to other European adolescents and that maximal oxygen uptake scores of the junior surfers were comparable to the values presented by Mendez-Villanueva and Bishop (2005) for regional level adult surfers. The power outputs associated with maximal oxygen uptake was significantly related to ranking in this UK group of high performance junior surfers and as such might be an important factor for achieving success when considering the physiological profile of junior surfers. Coaches can use this as a predictor of ability within their own teams but care should be taken if using power outputs described in the current study as a comparison due to variations in protocols and equipment.

Further studies should seek to identify whether the factors used in this study are able to predict ability in a heterogeneous sample or differentiate between groups of varying ability. Power output associated with maximal oxygen uptake and blood lactate thresholds have been found to be related to performance in a number of studies, though the reported power outputs and values of maximal oxygen uptake vary significantly between these studies and the participant compliance to blood sampling can be difficult, especially with children. The protocol and the type of ergometer used should aim to be standardised across studies and the use of isokinetic ergometers that allow for precise control of power output.

Chapter 4.0 The effects of creatine supplementation on repeated upper body anaerobic power and competitive performance in intermediate ability surfers.

This chapter formed the basis of the oral presentation "Oral creatine supplementation has no significant effect on body composition, repeated upper body anaerobic power and competition performance in club level surfers" presented at the 2009 British Association of Sport and Exercise Sciences annual conference in Leeds an abstract of which was published in the *Journal of Sports Sciences,* 27: 4, S1-S133 a copy of which can be found in Appendix 4.

4.1 Background to the study

The action of surfing is described as an intermittent exercise that comprises bouts of high intensity exercise interspersed with periods of low intensity activity and rest utilising both the upper body during paddling and "popping up", with the lower body being predominantly responsible for board control during surfing and the upper body used to generate angular accelerations when turning (Lowdon (1983), Meir *et al.* 1991, Mendez-Villanueva 2003, Mendez-Villanueva and Bishop 2005, Mendez-Villanueva *et al.* 2006, Eurich *et al.* 2010).

Many sports are intermittent in nature with activity fluctuating from (short) periods of maximal or near maximal work to longer periods of moderate and low intensity activity (Glaister 2005). Some examples of sports which have been researched as intermittent sports include racquet sports such as squash, badminton and tennis

(Docherty 1982) and team sports such as soccer, Australian rules football, field hockey, rugby union and Gaelic football (Spencer *et al.* 2005). All of these sports involve walking or running as the primary mode of locomotion and thus are inherently different to surfing. However they do provide a framework by which it is possible to analyse surfing. During field sports the approximate duration of high intensity efforts is reported to be 4-7 seconds of which 2 seconds is attributed to all out sprinting with the ratio of high intensity activities to low intensity activities ranging from 1 : 6 to 1 : 14 (Docherty *et al.* 1988, Brodowicz *et al.* 1990, Bangsbo *et al.* 1991). During racquet sports high intensity efforts (rallies) are on average 5 - 10 seconds with a work to rest ratio of 1 : 1 to 1 : 5. There is a paucity of data regarding the likely time spent in each aspect of surfing activity (riding, paddling, waiting etc) with authors reporting only overall time and percentage time for each activity (Meir *et al.* 1991, Mendez-Villanueva 2003). However Lowdon *et al* (1996) stated that the average ride during the Quicksilver trials and the Ripcurl main event held at Bells Beach, Australia was 23.7 seconds. Furthermore Mendez-Villanueva *et al.* (2006) reported that the average length of ride was 11.6 seconds (range 1- 44 seconds), paddling was 30.1 seconds (range 1-286 seconds) and stationary was 37.7 seconds (range 1-4) standard deviations were not reported and on average 5 waves were ridden in each 25 minute heat. Mendez-Villanueva *et al.* (2006) stated that the average duration of arm paddling (30.1 seconds) and rest (37.7 second) gave a work to rest ratio of 1 : 1.25. This calculation neglects the work done during the wave riding portion of the activity. Including the wave riding activity of 11.6 seconds with the arm paddling of 30.1 seconds gives work to rest ratio of 1 : 0.9. Using this methodology it would appear that the work to rest ratio of surfing is higher than in any of the other sports researched thus far.

4.1.1 Metabolism during sprints

There has been significant research into the contribution of aerobic and anaerobic metabolism during sprint and maximal exercise. Spencer *et al.* (2005) performed a review of the literature regarding the physiological and metabolic responses of repeated sprint activities which were specific to field based team sports. They summarised the findings of Medbø *et al.* (1999) who found that during 30 second maximal bicycle sprint; aerobic processes provided 38%, anaerobic processes 45% and alactic anaerobic processes (ATP and phosphocreatine [PCr] breakdown) 17 % of total energy production. Furthermore during 10 seconds of sprint cycling Medbø *et al* (1999) calculated the relative contribution of anaerobic glycolysis and alactic processes to 47% and 22% respectively; suggesting a contribution of 31% from aerobic processes. This along with the study of Spencer and Gastin (2001) suggests that during sprints of 12 – 22 seconds aerobic processes only contribute ~ 30% of the energy required.

These findings might be relevant to surfing if time spent paddling for a wave, riding a wave and then paddling back out again is considered as a single exercise bout. According to Mendez-Villanueva *et al.* (2006) this single bout of activity is on average 41.7 seconds long and would be repeated with every wave caught which has found to be approximately five waves per heat (Mendez-Villanueva *et al.* 2006). This would require a considerable contribution of energy from the aerobic system, possibly greater than 38% as calculated by Medbø *et al.* (1999).

In order to properly assess energy system contribution during sprint exercise accumulated oxygen deficit and muscle biopsies which allow the quantification of muscle metabolites are generally performed (Spencer *et al.* 2005). Intramuscular adenosine triphosphate (ATP) is commonly accepted as 20-25 mMol.kg^{-1} dry mass in the reference male and it is suggested that the maximum depletion of this store is approximately 45% during sprints of 30 seconds, 14-32% depletion during exercise of 10-12.5 seconds and 8-16% during 6 second cycle sprints (Jones *et al.* 1985, Medbø *et al.* 1999, Eurich *et al.* 2010). These figures suggest that during short duration maximal exercise there is only a relatively small reduction in the concentration of ATP due to the energy buffering capacity of phosphocreatine (PCr). Intramuscular PCr stores are reported to be 75-85 mMol.kg^{-1} dry-mass and it is suggested by Spencer and Gastin (2001) that this amount of PCr can provide enough energy for 5 seconds of maximal sprinting. With the contribution of anaerobic glycolysis and aerobic ATP metabolism during short duration sprint exercise, PCr stores are not typically completely depleted with maximal sprinting of 10-12.5 seconds reducing PCr by 40-70% and shorter duration exercise of 6 and 2.5 seconds resulting in reductions of 35-55% and 26% respectively . Hirvonen *et al.* (1992) found that the ability to deplete PCr was positively related to sprint performance, however it is unclear whether an athlete's ability to increase PCr degradation during a one-off sprint is trainable or affected by creatine supplementation (Stathis *et al.* 1994).

The research cited above relates to lower body exercise in the form of cycling and sprinting, and to date there is a paucity of research regarding energy system contribution during upper body sprinting exercise. Additionally the published studies relate to “one-off” sprint performance which correlates to surfing in the instance of a surfer paddling into one wave. However surfing involves repeated periods of sprint paddling, stand-up surfing, paddling to the line-up and recovery. To gain further insight into the physiology of surfing it is necessary to review the literature surrounding repeated sprint exercise.

Bogdanis *et al.* (1996) investigated changes in muscle metabolism during two, 30 second cycling sprints separated by 4 minutes of recovery and reported a reduction in anaerobic energy production of approximately 41% in the second sprint. This was accompanied by only an 18% reduction in total work, and a 15% increase in $\dot{V}O_2$ during the second sprint. These findings are supported by McCartney *et al.* (1986) and Trump *et al.* (1996) who also found a significant decrease in glycolysis in repeated 30 second sprints without a proportional decrease in power output. A similar effect was found during repeated 6 second sprints with no increase in blood lactate level during the final (tenth) sprint (Gaitanos *et al.* 1993). These results would appear to be relevant to the repeated sprint activity involved with sprint paddling into waves and paddling back to the peak during surfing activity. Research has shown that ATP depletion during multiple sprints is limited to approximately 45% of that seen in single sprints. However there is significant variation in ATP depletion dependent upon the intensity of the exercise with maximal exercise causing the greatest reductions ATP concentration (Spencer *et al.* 2005). Bogdanis *et al.* (1996) found that power output during the initial 10 seconds of repeated 30 second sprints is significantly correlated to PCr resynthisis with the initial fast phase of PCr resynthesis being dependent upon oxygen availability . Dawson *et al.* (1997) studied the effect of five, 6 second sprints interspersed with 24 seconds of passive rest and found that following 3 minutes of recovery PCr was only 84% of resting levels. This has important implications when considering surfing, as it is reported that rest periods during competitive surfing are only on average 37.7 seconds long (Mendez villenauva *et al*, 2005). Therefore it is unlikely that there is sufficient time for full PCr replenishment to occur and it is feasible that there will be a decreasing contribution from PCr to the total ATP production.

During surfing it is likely that much of the physiological recovery might take place during paddling activities as paddling contributes 35-54% of the total surfing time (Meir *et al.* 1991, Mendez-Villanueva and Bishop 2005, Mendez-Villanueva *et al.* 2006, Farley *et al.* 2012). Similar findings have been found in other sprint sports; Spencer *et al.* (2004) found that 95% of the recovery from sprint bouts during field hockey was active in nature with the majority being in the form of jogging. Lab based studies (Spencer *et al.* 2008) have shown that PCr concentrations following six, 4 second sprints, with 21 seconds of either active or passive recovery were significantly lower following the active recovery, suggesting that active recovery might hinder PCr resynthesis when undertaken during bouts of repeated-sprint exercise. In summary it is evident that the contribution of anaerobic glycolysis is reduced during repeated sprints and that aerobic metabolism plays an increasing role in energy production with the rate of PCr resythnesis being significantly correlated to subsequent performance

Spencer *et al.* (2005) suggested that the assessment of various physiological and performance measures (heart rate, $\dot{V}O_2$, blood lactate concentration and power output) during a repeated sprint ability test (RSA) would enhance the understanding of repeat sprint sports performance. The RSA would include a number of sprint repetitions and recovery periods which were comparable to the actual sporting performance; the duration and intensity of these bouts could be designed based upon time motion analysis of the activity. The mode of exercise used in these tests would have to be specific to surfing activity (i.e. paddling) however to fully replicate surfing is likely to be highly challenging in comparison to many sports which only include lower or upper body locomotion and not a combination of upper body (paddling) and lower/whole body (surfing) interspersed with periods of rest. However it is likely that RSA will help in the assessment of the physiological parameters of surfers.

4.1.2 Creatine supplementation

Creatine is an amino acid, which can be synthesised endogenously from glycine methionine and arginine, or obtained, in small quantities from meat and fish in the diet (Williams *et al.* 1999). Creatine is stored in the muscle as free creatine and phosphocreatine. The body stores creatine in both the free (Cr) and phosphorylated forms (PCr). The total amount of the two forms is called the total creatine (TCr). TCr stores approximate to 120 g in a 70 kg male with approximately 95% of this in skeletal muscle, with higher concentrations in fast-twitch muscle fibres (Kreider *et al.* 1998). The remaining 5% is found in the heart, brain and neural tissues (Siu *et al.* 2004). Short term supplementation of creatine (15 to 25 $g.d^{-1}$ for 5-7 days) has been reported to increase the availability of creatine and phosphocreatine during high intensity exercise, maintaining adenosine triphosphate (ATP) levels and improving maximal power, strength, work performed during sets of maximal effort, single sprint performance and work performed during repetitive sprint performance (Kreider 1999).

Research into the role of creatine in the human body has been taking place since its discovery in 1832 by the French scientist, Michel Eugene Chevreul (Kreider, 1998). By the beginning of the 20th century there was already literature pointing to the important function of creatine in muscular contraction, due to its specific distribution within the body's tissues and its absence from normal urine. In 1923 Chanutin, observed that when creatine was administered in the diet a large amount was retained by the body (Greenhaff 1997).

According to Volek *et al.* (1997) creatine serves several important functions within cell metabolism. Firstly phosphocreatine acts as a temporary energy buffer acting as a donor of phosphate for energy production. The maintenance of ATP during rapid increases in energy demands is met by the rapid breakdown of PCr. Creatine also acts as a spatial energy buffer as there is evidence of a diffusion of Cr and PCr between mitochondrial sites of production and sites of utilisation (in the case of muscle, the myosin head) (Volek and Kraemer 1996). This is termed as the PCr energy shuttle (Bessman and Savabi 1990). Volek and Kraemer (1996) describe the PCr shuttle as having 3threedistinct areas:

1) A peripheral terminus, located at the site of utilisation, containing the specific isoenzymes of creatine kinase (CK), which acts to rephosphorylate the ADP produced from muscular activity.

2) An energy-generating terminus located at the mitochondria where free Cr interacts with the specific isoenzymes of CK, and PCr is formed from mitochondrial ATP.

3) An intervening space between these two areas where Cr travels from the peripheral terminus to the energy generating terminus and PCr travels from the energy-generating terminus to the peripheral terminus.

When the CPK reaction is in the favour of ATP regeneration PCr also acts as a buffer to protons (H^-) that are the products of ATP hydrolysis. This buffering capacity helps prevent the acidification of cells and maintains a normal pH (Volek and Kraemer 1996).

According to Bessman and Savabi (1990) creatine has been shown to stimulate the biosynthesis of myofibrillar protein in differentiating muscle cells both *in vivo* and *in vitro*. The response is concentration dependent over the range of 10-100 μM and maximal over the range of 100 μM to 250 μM. It is important to note that the normal plasma concentration is 100 μM as this has implications related to supplementation dosages. Creatine also stimulates the uptake of amino acids into the contractile proteins, suggesting that the amount of load-bearing protein could hypertrophy in proportion to the rate of PCr hydrolysis (Williams *et al.* 1999).

The most commonly used creatine loading protocol found within the current research is to ingest a total of 20-30 g of creatine a day, usually creatine monohydrate in four equal doses (5-7 g) dissolved in approximately 250 ml of fluid. The dosage is usually taken early morning, noon, afternoon and evening for a period of 5 days. When based upon body mass the recommended dosage is 0.3 $g.kg^{-1}$ body mass per day for a period of 5 days (Kreider 1999). The general dosage was first implemented by (Harris *et al.* 1992). However Harris later admitted that the reason why he selected the 20 g a day regime was because he had to fly to Sweden on the Monday and return to England the following Sunday (Williams *et al.* 1999). In that short time Harris had to ensure that the athletes were truly loaded. Thus he devised the idea of an acute high dosage of 20 g a day for five days based upon logistical pressures rather than scientific insight. Hultman *et al.* (1996) proposed a lower dosage of $0.3g.kg^{-1}$ body mass for the first five days and then $0.073g.kg^{-1}$ body mass thereafter. This strategy has been shown to be just as effective over a period of 28 days as the higher dosage strategy. However the only established drawback with using the higher dosage would relate to waste and cost which given the current price of creatine is negligible (Kreider 1999).

Harris *et al.* (1992) found that a 5 g dose was sufficient to raise the plasma concentration of Cr to a peak of 500μMol/l or more. It was reasoned that as Cr entry into muscle occurs via a saturable process (along a concentration gradient) and therefore plasma concentrations needed to be high. Due to the short half-life of Cr in plasma (1-1.5 h) it was suggested by Harris *et al.* (1992) that the Cr dosage needed to be taken regularly to maintain high plasma levels to facilitate entry into the muscle. Greenhaff (1997) agreed that a 5 g supplement will increase Cr plasma levels sufficiently over a 1 h time period to stimulate muscle Cr uptake. Greenhaff (1997) added that using a dosage of greater than 20 g a day for five days did not serve to improve muscle uptake. Harris *et al.* (1992) suggested that there is an upper limit of the TCr pool of approximately 160 $mMol.kg^{-1}$ dry mass, which once reached supplementation becomes ineffective.

Once creatine loading has been completed, Hultman *et al.* (1996) found that the elevated TCr could be maintained by the administration of a 2 g a day dose during a 30 day trial, this was compared to a gradual decline in Cr levels in the non-maintenance group. Hultman *et al.* (1996) also demonstrated in the same study that a longer term loading protocol of 3 g a day for 28 days lead to similar increases in muscle Cr as the higher dose and might in fact be more cost effective as less creatine is lost from the system.

Theodorou *et al.* (1999) found that the performance of elite sprint swimmers was improved following an acute loading of creatine (25 g per day for four days), however long term supplementation for two months (5 g of creatine a day) did not benefit the creatine group significantly compared with the placebo group. Theodorou *et al.* (1999) did not take any direct measures of total muscle creatine concentration, therefore creatine levels could not be ascertained at the end of the long term supplementation.

The ergogenic effects of creatine supplementation are related to the role of Cr and PCr in muscle bioenergetics Hultman *et al.* (1996) suggested that creatine supplementation could be ergogenic for high intensity and very high intensity exercise by: (1) increasing the resting levels of PCr to act as an immediate buffer to ATP use during exercise, (2) Increasing the levels of free Cr allowing increased rates of PCr resynthesis during and after exercise, and (3) Enhanced buffering of hydrogen ions (H^+) to prevent high acidity of the cell. It is also noted that creatine supplementation is related to increases in fat-free mass and strength (Kreider 1999).

The aim of this study was to assess the effects of short term (20 $g.day^{-1}$for five days) creatine supplementation on repeated upper-body anaerobic power and competitive performance in intermediate ability surfers.

4.2 Methodology

4.2.1 Participants

Following institutional ethical approval (Appendix 4.0) and completion of informed consent, *n* = 17 club level male surfers (mean: age 23.1 ± 4.2 years, stature 179.7 ± 9.9 cm, body mass 72.0 ± 9.9 kg) were recruited from the student population studying marine sports related undergraduate degrees at the University of Plymouth.

4.2.2 Procedures

The experimental protocol involved nine weeks of testing; in the first week the participants were tested to measure baseline scores. The baseline testing comprised of a body composition assessment, repeated upper-body anaerobic power (RUBAP) tests, and a performance in a surfing competition. The participants were then randomly selected into either the creatine or placebo group in a double blind manner. Participants then underwent a five day loading phase of creatine ofr placebo before returning to the laboratory for further body composition and RUBAP testing. Participants then participated in another surfing competition before entering a four week washout period before the groups were reversed and the testing repeated.

4.2.1.1 **Repeated upper-body anaerobic power (RUBAP) testing**

The RUBAP test was performed on a bench mounted Monark Ergomedic 874E (Monark, Varberg, Sweden) with the Cranlea & Co, Wingate sensor (Cranlea & Co, Bourneville, United Kingdom) (See fig 4.1).

Figure 4.1 Participant undergoing repeated upper-body anaerobic power (RUBAP) testing.

The resistance for the RUBAP was set at 6% of body mass following the recommendations of (Smith 2007) and was performed as exercise based upon the demands of surfing competition (Mendez-Villanueva 2003). The test involved 120 (50% of overall time) seconds of unloaded arm cycling followed by 105 seconds (43% of overall time) of passive recovery before commencing a 15 second maximum effort with load (6.25% of overall time) This process is then repeated five times to produce 20 minutes of exercise. This roughly replicates the temporal dynamics reported by Mendez-Villanueva (2003) who found that within a 20 minute surfing heat 51% of the overall time was spent paddling, 42% of the time waiting stationary and 2.5% of the time surfing. The remaining 4.5% of the time was spent in miscellaneous activities such as wading, duck diving and swimming. The protocol combined sprint paddling, miscellaneous activities and surfing into the 6.25% of time spent performing the upper body maximal effort. The five bouts of exercise within the twenty minutes replicate analysis of surfing recorded by Mendez-Villanueva and Bishop (2005) who found the average wave count in a twenty minute heat was five waves. Thus the surfers would generally repeat a process of paddling, waiting, sprint paddling and surfing five times.

4.2.2.2 Body composition assessment

Stature was measured using a SECA stadiometer (model 220, SECA, Birmingham, United Kingdom). The subject is stood erect and barefoot, measurement was repeated until like measurements within 2mm were obtained. Height and body mass were measured using the methods previously described in section 2.2. Body Composition and total body water was measured using Bioelectrical Impedance Analysis (TBF300 MA, Tanita, Middlesex, UK) to identify non-responders (Kutz and Gunter 2003).

4.2.2.3 Surfing competition

The day following the baseline testing the participants competed in surfing competitions (Figure 4.2). The contests followed the International Surfing Association (ISA) rules for open competition and were judged by three ISA qualified judges. Points were awarded for position in the contest and also individual wave counts were recorded in each heat for each surfer. To encourage a sense of competition and maintain participant engagement the contests were run as a series with prizes available for the top three surfers following completion of all four contests. Surfers were allowed to compete on either long or short boards but the competitions were judged based on the short board criteria. The locations for the surfing competition were selected to achieve similar wave size and wind orientation during each event. The dominant wave size during the surfing competitions was 1.0-1.2m

Figure 4.2 Participants competing as part of the study.

4.2.3 Statistical analysis

A two-way repeated measures ANOVA was performed all measured variables with levels of time (pre-loading first loading phase, post-loading first loading phase, pre-loading second phase, post-loading second phase) and condition (creatine or placebo). Further analysis was performed with a two-way repeated measures ANOVA between the delta (change) values for creatine and placebo conditions during the first and second loading phases. All statistical analyses were performed in IBM statistics for windows 20.

4.4 Results

The following section presents the data that were gathered through the study. Table 4.1 shows the mean and standard deviations for all measures. The values for all measures were non-significantly different at baseline suggesting that the groups were balanced. There were non-significant differences between creatine and placebo in the raw scores and the delta values for all measured variables of the (P > 0.05) and there was a non-significant interaction between time and supplement (P > 0.05).

Table 4.1 Showing pre- and post-supplementation values for measured variables

	Creatine mean ± s		Placebo mean ± s	
	Pre	Post	Pre	Post
Body Mass (kg)	72.1 ± 10.1	72.4 ± 10.2	72.9 ± 10.0	72.68 ± 9.9
Total body water (kg)	47.6 ± 5.7	48.2 ± 5.6	48.7 ± 5.3	48.48 ± 5.5
Peak power (watts)	664.3 ± 129.1	686.3 ± 143.5	687.1 ± 143.5	696.0 ± 186.2
Average power (watts)	504.6 ± 99.8	509.3 ± 70.7	515.0 ± 75.0	500.7 ± 108.9
Average wave count (1)	2.24 ± 2.3	3.00 ± 2.2	4.4 ± 1.9	3.6 ± 2.0
Competition points	170.6 ± 199.3	200.0 ± 171.0	160.0 ± 135.2	176.5 ± 178.6

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The two way repeated measures ANOVA performed on the change (delta) values of the peak power and average power for each of the individual sprints of the RUBAP protocol found no significant differences in the change in average power (Figure 4.3) or peak power (Figure 4.4).

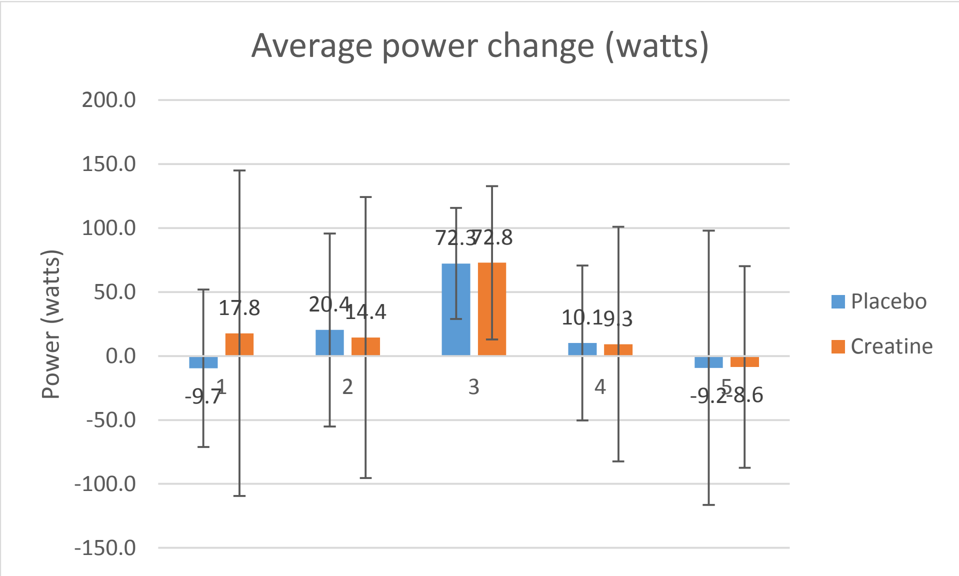

Figure 4.3 changes in average power from following placebo or creatine supplementation.

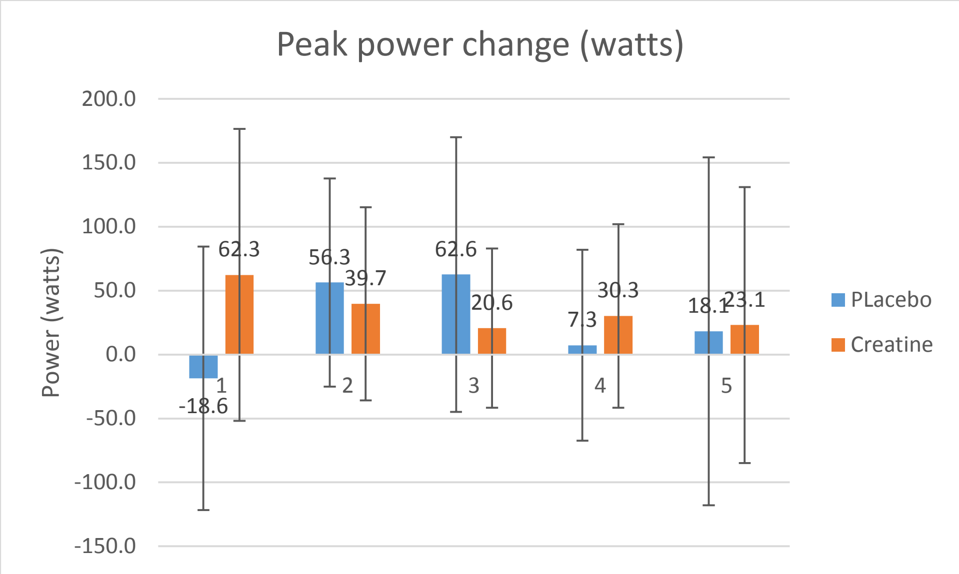

Figure 4.4 changes in peak power from baseline following placebo or creatine supplementation.

Figure 4.5 shows the wave conditions measured from wave buoy data during both loading periods and the period of time between each loading phase. There were large waves (7 m with 9.8 second period) immediately prior to the baseline testing. There were suitable waves for surfing throughout the first loading period (ranging from 2.8 m and 6.2 second period to 4.5 m and 7 second period). There was also significant wave activity during the 2nd loading phase with waves of 4.8 m and 9.2 second period.

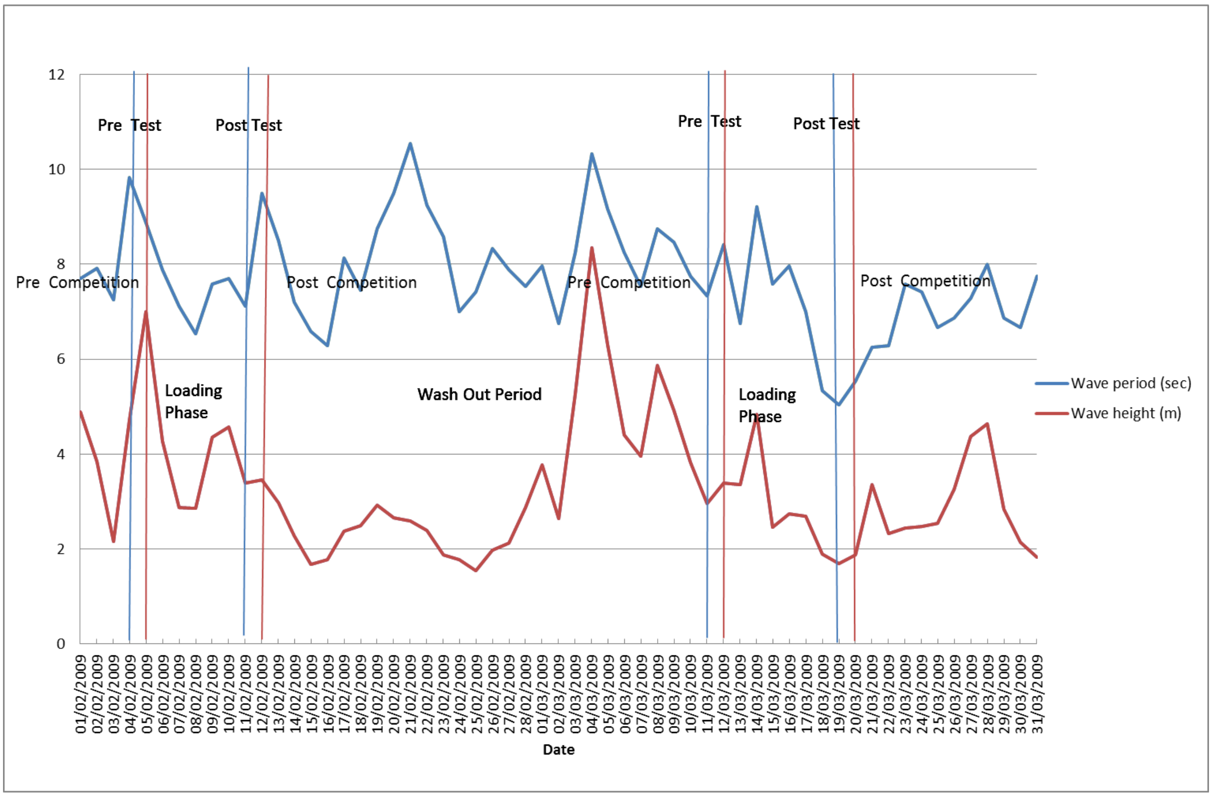

Figure 4.5 Wave conditions (wave height and period) during the study with the timings of loading and the pre and post supplementation laboratory testing (vertical blue line) and competitions (vertical red lines).

4.4 Discussion

Table 4.1 gives an overview of the results of the study, considering the body mass results for the pre- and post- supplementation measures for both groups, non-significant differences were found between the groups or pre- to post- supplementation in either the placebo or creatine condition. The placebo group did demonstrate a small average reduction in body mass pre- to post- supplementation of 190g where the creatine group had a small but insignificant average increase of 330g. Increases in body mass through creatine supplementation are commonplace and are often cited as an indication of a successful loading strategy (Kutz and

Gunter 2003). Williams *et al* (2011) suggested that creatine supplementation might influence body mass by increasing cellular water, stimulating protein synthesis or reducing protein degradation. Although the increases of body mass in the current study were not statistically significant they should be considered in relation to the decrease of body mass found in the placebo group and thus it can be assumed that the creatine loading was successful. The evidence of a successful loading strategy is also supported by the non-significant increase in total body water (TBW) seen in the creatine group compared to the small but non-significant reduction of TBW in the placebo group over the supplementation period (Powers *et al.* 2003).

The data from the RUBAP was averaged across the five sprints to find whether there was any effect of the creatine supplementation in comparison to the placebo across both bouts of supplementation in terms of the peak or average power. The analysis revealed an insignificant increase in peak power in both the creatine and placebo groups with a non-significant increase in average power for the creatine group compared to a non-significant decrease in the values for the placebo group. From the above data it can be surmised that creatine supplementation did not increase performance in the laboratory-based repeated upper body anaerobic power test. Although there is precedent of creatine supplementation failing to elicit an ergogenic response in anaerobic sprint and strength performance tests even when there has been a measured increase in total muscle creatine (McKenna *et al.* 1999) these results are counterintuitive as it can generally be expected that creatine supplementation of this nature would improve anaerobic power indices; especially within controlled laboratory conditions (Geladas *et al.* 2005, Garrido *et al.* 2012).

Figures 4.3 and 4.4 show the changes in the average and peak power values respectively for each sprint of the RUBAP. It is clear that there is no consistent improvement in either measure through the creatine supplementation. Both the placebo and creatine showed increases in peak power output in all sprints (with the exception of the first sprint in the placebo condition) with the largest increases in the third sprint.

The lack of an effect of the supplementation protocol on the laboratory tests is supported by the lack of any significant increase in the number of waves caught during the study as a result of the creatine supplementation in relation to the placebo. There were non-significant effects of the creatine supplementation on the points scored during the competition following the supplementation protocol. The lack of an effect of creatine supplementation on performance of sports specific skills has been demonstrated previously (Richards and Palmiter-Thomas 1996) and the current study looked at surfing performance as whole, which was assessed by the judged performance of each of the surfers and the actual numbers of waves caught. The number of waves that are caught during a session can theoretically be influenced by a number of factors that are intrinsic to the surfer; aerobic fitness; specifically maximal oxygen uptake, anaerobic fitness – power and capacity, intermittent endurance and strength and power can all influence a surfers performance (Mendez-Villanueva and Bishop 2005). However there are a number of external factors that can influence surfing performance such as equipment, wave conditions, and the effect of other surfers competing for waves or standing in competition (Mendez-Villanueva and Bishop 2005). (Mendez-Villanueva *et al.* 2010) evaluated the variability in surfing performance and determined that surfing performance is highly variable and largely dictated via wave conditions which can vary from location to location and minute by minute at any given location and as such the detection of any worthwhile change in performance might take several observations. Thus it is possible that any changes in performance as a result of the supplementation might have been disguised by the wave conditions on the day of testing.

Figure 4.5 gives the variation in wave size and period for the duration of the study. Surfing activity is by its nature sporadic and dictated by wave conditions which can result in long periods where surfers are unable to engage in their activity and thus when the right conditions are available it is difficult to dissuade them from participating in surfing activity. Although surfers were requested to refrain from surfing activity outside of the study; surfers exhibit a strong drive to surf when conditions permit and are single minded in their pursuit of their satisfaction to their addiction of surfing (Ford and Brown 2006). During the period of loading and prior to any testing the high quality wave conditions during these time periods resulted in many participants surfing extensively which was confirmed verbally in discussion relating to the activities the participants had undergone during the testing period. During the two days before theinitial baseline testing the wave conditions were 6ft with a 10 second wave period, which is very favorable for surfing. This meant that some of the surfers could have been fatigued during the baseline testing. Furthermore, reasonably good (for the UK) conditions prevailed through the loading phase and during the post-loading testing with 1.2m waves with 7-9 second period, so it is also possible that the surfers could have been fatigued on the day of the post-supplementation testing. This might have confounded the results of the study however it could be argued that this supports the “real world” validity of the study and it is not believed that this would skew the data as participants in both groups were engaging in surfing activity. The conditions for the baseline testing and the post supplementation were relatively similar with 1.2m 8 second period and 1m 8.2 second period waves respectively on the same beach at similar points of tide, with similar wind conditions. Thus the conditions during this part of the testing were similar and should have allowed a valid measure of the effect of supplementation on surfing performance if both groups were in comparable condition in terms of fatigue and ability. Felder *et al* (1998) found that surfers generally had inadequate energy intake to maintain energy balance during training and competition, thus it is likely that following the extended period of wave activity prior to and during the loading phase the participants might have been in a state of energy deficit during the post supplementation testing.

There was significant wave activity during the wash out period with an increase wave size (3-8ft) with reasonably good wave period (7-10 seconds) in the week prior to the second baseline testing. If we assume that during this period the participants were surfing regularly as is likely, it is also possible that the participants were both fatigued and in a state of energy deficit during these tests. The wave conditions deteriorated during the second loading phase with waves of 3ft and 7 second period during the second baseline testing to 2ft waves with 6 second period during the final performance assessment. Due to the wind direction during these two surfing assessment sessions, it was necessary to use different beaches with different orientations to achieve similar surfing conditions. This meant that although the waves were of a similar size, with similar relative wind directions the actual shape of the wave and intensity of the break would vary between the bouts of testing.

To truly assess whether creatine supplementation can increase performance in surfing it would be necessary to ensure that all participants were matched for ability from the outset. However the results of this study show that there were non-significant differences at baseline in competition points (Creatine = 170.9 ± 199.3 points, Placebo = 160.0 ± 135.22 points) or post-supplementation (Creatine = 200.0 ± 199.3 points, Placebo = 176.5 ± 178.6 points). There is an insignificant increase in the number of waves caught during the pre and post supplementation competitions. This could equally be argued to be either the result of the creatine supplementation or the lower wave period during the post-supplementation competition resulting in more frequent but smaller waves. In contrast the placebo group had a higher wave count in the first competition than the post supplementation competition. The differences in wave count equated, on average, to less than one wave and so it could also be that these differences are a result of the inherent high variability in surfing performance (Mendez-Villanueva *et al.* 2010).

4.5 Conclusions

This study concludes that 5 days of supplementation with 20g a day of creatine monohydrate did not cause any significant changes in body mass, TBW, anaerobic power or surfing performance. The loading strategy did not result in any significant enhancements in repeated sprint peak power.

The small improvements in peak anaerobic power that were measured in the lab did not transfer to any measurable improvement in surfing performance in the participants of this study. The inability to detect any effect of creatine supplementation on surfing performance might be due to the individual performances of the surfers in the study who were of intermediate ability; the variation in wave conditions at each testing occasion; or the effect of the varying levels of activity during the loading phase (s) as a result of favourable conditions during these time periods and the sporadic condition led nature of surfing.

Future studies are required to evaluate whether any relationship exists between the RUBAP indices and surfing performance, utilising a number of competitions to achieve the ranking of the surfers in relation to the laboratory tests.

If creatine supplementation is to be further evaluated using the RUBAP protocol then a familiarisation protocol must be utilised to ensure that any learning effect does not impact on the results. Where possible the results of multiple performance measures such as attempted waves, overall power output during the session, and maximum paddling speed should be used to accommodate the variation in surfing performance and it is recommended to use advanced surfers to minimise variations in performance.

Chapter 5.0 The effect of wave size and period on the physiological demand and performance indices of surfing.

5.1 Background to the study

As described in Chapter 1 surfing is an exercise which is characterised by surfers paddling out through the surf zone in the prone position performing “duck dives”, “press ups” or “turtle rolls” as required to prevent incident with oncoming waves until they reach the area beyond the breaking waves known as the “line-up”. Once in this area the surfer will wait until a suitable wave approaches, then with some powerful arm strokes the surfer will propel the board forwards towards the shoreline in order to gain enough speed to catch the wave. Once the surfer catches the wave they will “pop-up” to their feet and ride laterally along the wave performing a series of functional and perhaps some extravagant manoeuvres. They will continue along the wave in this manner adjusting their ride to remain in the “pocket” of the wave until either, they fall off, the wave “closes out” or the wave flattens. The surfer will then repeat the process.

The activity profile of surfers in this has been previously described in Chapter 1 of this thesis with surfers participating in activities of waiting (28.0-42.0% of total time), paddling (35.0-54.0% of total time) , riding (3.8-8.0% of total time) and miscellaneous activities (2.5-5.0% of total time) (Meir et al. 1991, Mendez-Villanueva and Bishop 2005, Farley et al. 2012). The physiological result of meeting the demands of surfing has been found to cause surfers to have an average heart rate during surfing ofbetween 64.4% and 85.0% of their laboratory tested maximum heart rate (Meir et al. 1991, Mendez-Villanueva and Bishop 2005, Farley et al. 2012). Farley et al.

(2012) further developed the analysis of surfing by using GPS to identify the total distances travelled and the representative speeds over the session.

The appropriateness of the wave conditions for the surfer to maximise the enjoyment of their surf session will be dictated by the swell conditions that produce the breaking waves (Chapter 1) and the level of their ability that allows them to cope with such wave conditions. Thus far no study has described the relationship between wave characteristics, surfer ability and how this affects physiological response and the performance profile of the surfers during surfing sessions.

5.1.1 Global Positioning Systems (GPS) in sports analysis

Global positioning systems (GPS) use 27 orbiting satellites that emit coded signals at the speed of light. The GPS units receive signals from at least three satellites to locate position and using changes in position over time can calculate velocity of an individual (Larsson 2003). GPS has been found to be a reliable method of assessing location and speed during human locomotion (Townshend et al. 2008) and has been used in a wide variety of sports such as rugby (Cahill et al. 2012), field hockey (Macutkiewicz and Sunderland 2011), soccer (Castagna et al. 2010), cricket (Petersen et al. 2010) and surfing (Farley et al. 2012). The issues of accuracy and validity of the GPS systems have to be considered in relation to the costs and the practicality of the system. GPS systems currently sample between 1Hz and 10Hz with higher cost being associated with the higher sampling rate but also with increased precision and reliability of measurement (Varley et al. 2012). The 1Hz GPS units have been found to be less reliable at higher speeds and during non-linear movement (Gray et al. 2010) but the reliability issues need to be weighed against the cost and other practical considerations such as size, integration with other devices such as heart rate monitoring and appropriateness in consideration of the environment in which GPS is used; such as whether the system is waterproof, and impervious to the marine environment.

5.1.2 Heart rate monitoring in sport and exercise

Heart rate monitoring has become a widely used aid in the assessment and prescription of exercise and training (Laukkanen and Virtanen 1998, Achten and Jeukendrup 2003). The assessment of heart rate has been performed for over 200 hundred years; initially through placing an ear on the patient's chest, then using the stethoscope and subsequently with the electrocardiograph (ECG) which was developed in the early 20th century (Achten and Jeukendrup 2003). Wireless heart rate monitors were introduced in 1983 allowing the monitoring of heart rate during exercise and in sports situations. The utilisation of the relatively small and simple to use heart rate monitors resulted in the adoption of the objective measure of heart rate as an indicator of exercise intensity over the previously used measure of perceived exertion (Laukkanen and Virtanen 1998). The validity and accuracy of wireless heart rate monitors has been investigated thoroughly and the devices that use chest electrode sensors have consistently been found to be accurate and reliable (Leger and Thivierge 1988, Macfarlane et al. 1989, Seaward et al. 1990, Godsen et al. 1991, Kinnunen and Heikkila 1998, Goodie et al. 2000). Leger and Thivierge (1988) compared 13 different heart rate monitors that utilised electrodes at the chest, finger or photo cells at the earlobe with ECG. Only the four monitors that used chest electrodes were found to be reliable. Macfarlane et al. (1989) found that the bias and variability of heart rate monitors was less than 1 b.min-1 across their functional range when compared to ECG. The correlation coefficient between heart rate monitors and ECG during laboratory testing of treadmill walking and running and nordic track skiing across n = 24 subjects was found to be 0.998 suggesting that the two measures are strongly correlated (Macfarlane et al. 1989). Godsen et al. (1991) compared heart rate measured through wireless heart rate monitors and compared them to values measured through traditional ECG measurements. The study found that the values from the wireless heart rate monitor were within 6 b.min-1 of the values measured through ECG 95% of the time. These studies suggest that wireless heart rate monitoring is a valid and reliable measure of heart rate during exercise.

It is well accepted that there is a linear relationship between heart rate and $\dot{V}O_2$ up to near maximal work rates and that heart rate can be used to predict exercise intensity relative to $\dot{V}O_{2max}$ and the energy expenditure associated with work at a given heart rate (Mc Ardle et al. 2007). The linear relationship between heart rate and $\dot{V}O_2$ is relatively consistent however it should be considered that small variations in low level activity, such as small movements when at rest, can have a considerable effect on heart rate but minimal effect on energy expenditure (Achten and Jeukendrup 2003). The heart rate $\dot{V}O_2$ relationship has also been found to be affected by the type of activity and the posture of participant and as such heart rate / $\dot{V}O_2$ relationships are sports specific (Andrews 1966, Li et al. 1993). Achten and Jeukendrup (2003) suggest that during intermittent exercise the heart rate / $\dot{V}O_2$ relationship might not be that accurate due to heart rate lag. The adaptation of HR rate to exercise intensity is relatively slow and because of this rapid increases in intensity might not immediately elicit the heart rate that would be associated with the given work rate with 3-5 minutes of acclimatisation to that intensity. Moreover when exercise intensity is reduced the heart rate will remain elevated before gradually reducing to the heart rate associated with the lower intensity.

This process of delayed response suggests that the heart rate associated with a given intermittent exercise intensity might not be reflective of the exercise at that instance. However, given the delayed increase of heart rate at the onset of increased work rate and the associated delay in reduction of heart rate following the reduction of workload, it is probable that the heart rate profile over a given period of time is reflective of the $\dot{V}O_2$ associated with the overall activity but might be inaccurate for a given instant of activity. Furthermore the heart rate / $\dot{V}O_2$ relationship is specific to the mode of exercise and posture associated with the exercise which dictates that any laboratory procedures used to develop heart rate / $\dot{V}O_2$ relationships for the assessment of energy expenditure in the field should be designed to simulate the sporting activity as closely as possible (Achten and Jeukendrup 2003).

5.1.3 Exercise domains

During exercise there exist three domains of submaximal exercise that have been identified through the blood acid base status and pulmonary gas exchange (Whipp and Mahler 1980, Whipp and Ward 1990, Jones and Doust 2001). The three domains are identified as moderate, heavy and severe, and the physiological, metabolic and perceptual response of an individual differ considerable dependent on the domain that is studied (Jones and Doust 2001).

The moderate domain is identified as exercise which is below the intensity associated with the lactate threshold (Tlac); Tlac which is defined as the $\dot{V}O_2$ above which blood lactate rises above resting levels during incremental exercise (Wasserman et al. 1973). Exercise below the Tlac can be maintained for several hours and will be terminated due to substrate depletion, dehydration, musculoskeletal injury, psychological factors or in case of surfing where the exercise is typically performed in a cold and wet environment, hypothermia (Jones and Doust 2001). The energy demand during moderate exercise is generally met through an increase in pulmonary $\dot{V}O_2$ however this might take 2-3 minutes to meet the steady state demand. The deficit between the rapid increase in demand and the slower increase in $\dot{V}O_2$ is met by the utilisation of intramuscular oxygen stores, depletion of phosphocreatine and anaerobic glycolysis resulting in small but transient increases in blood lactate concentration which is rapidly removed resulting in the blood lactate concentration remaining at or near resting values (Jones and Doust 2001).

The heavy domain is defined as exercise above the Tlac and below maximum lactate steady state (MLSS). The MLSS can be defined as the highest exercise intensity that allows the blood lactate variables to stabilise during long term exercise with stable values of 2-5 $mMol.L^{-1}$ being achieved (Poole et al. 1990, Beneke 2003). Alternatively MLSS can be viewed as the exercise intensity above which blood lactate concentrations will continuously rise during continuous exercise. The determination of MLSS is a long process that requires the participant to complete a number of prolonged (~ 30 minutes) constant intensity exercise bouts with serial blood lactate measurements being taken during exercise. The bouts of exercise are repeated over a number of days with the intensity being increased each day with the MLSS being identified as the maximal exercise intensity during which blood lactate remains stable throughout the bout (Beneke 2003). The high number of blood samples and laboratory testing sessions required to measure MLSS have led to the development of a number of simpler tests to estimate MLSS. It has been identified that two lactate thresholds can be calculated during incremental exercise tests; the first being the Tlac and the second being the lactate turn-point (LTP). The LTP is defined as a sudden and sustained increase in blood lactate usually between 3-5 $Mmol.L^{-1}$ and is suggested to possibly provide a reasonable estimate of MLSS (Skinner and McLellan 1980, Jones and Doust 2001). The power output, velocity or exercise intensity associated with LTP has been found to be indicative of performance in various activities (Midgley et al. 2006, Van Someren and Howatson 2008) and is thought to be more meaningful for endurance performance than Tlac (Ribeiro et al. 1986, Aunola and Rusko 1992, Hofmann et al. 1994, Jones and Doust 2001). Due to the nature of blood lactate production and the similar relationships of MLSS and LTP to performance it is logical to assume that the relationship between MLSS and LTP proposed by Jones and Doust (2001) exists. However a search of the literature relating to this subject provided no empirical evidence of this relationship and indeed some evidence suggests the contrary (Smith and Jones 2001). Furthermore the assessment of the turn point is subjective and the actual turn point might not be clear, in some cases the 2nd threshold is not even present.

In the interests of maintaining objectivity some authors suggest the use of a fixed blood lactate concentration of 4 $mMol.L^{-1}$ and the power output associated with 4 mMol.L-1 blood lactate concentration was proposed by Mader et al. (1976). According to Jones and Doust (2001) this figure might have been based upon the suggestion that muscle lactate transporters become saturated at approximately 4 mM muscle lactate (Jorfeldt et al. 1978). Additionally it was noted that trained athletes could tolerate workloads associated with this level of lactate production for extended amounts of time and that increasing the workload resulted in continually increasing levels of blood lactate that lead to cessation of exercise (Heck et al. 1985).

The use of this fixed blood lactate concentration has received support from Kindermann et al. (1979) and Heck et al (1985) who demonstrated that mean blood lactate at maximum lactate steady state was 4.0 ± 0.7 mM (range 3.1-5.5 mM).

The third domain of exercise is the severe domain which is characterised as being above the LTP and as such blood lactate levels will increase continuously. Correspondingly $\dot{V}O_2$ will not achieve steady state and will increase continuously until the exercise is terminated or $\dot{V}O_{2max}$ is achieved (Poole et al. 1990).

Jones (2001) adapted the classification of the exercise domains to allow for training intensities to be prescribed from blood lactate, heart rate and $\dot{V}O_{2max}$ when supporting athletes. Jones (2001) describes these training zones as “easy”, “steady”, “tempo” and “intermittent”. The “easy” and “steady” zones are identified using the lactate threshold and lactate turn-point in the same respective manner as the moderate and heavy domains respectively. The “tempo” zone is defined as being above the Lactate turn point up to the heart rate that is associated with 90% of $\dot{V}O_{2max}$. Exercise above this intensity is defined as the “intermittent” zone. The easy zone would be used for training that is of long duration but intended as low intensity for the purposes of warm up or cool down. The “steady” zone would be where athletes would target the majority of their longer duration training with the “tempo” zone being used in activities lasting between 15 and 45 minutes dependent on whether the activity took place towards the upper or lower ends of this training zone. The “interval” zone would relate to high intensity aerobic work lasting 1-5 minutes in duration.

The significant relationship between lactate parameters and their utility in differentiating between surfers of different levels of ability have been discussed in chapter 3. However, thus far no research has attempted to relate the lactate parameters that are measured in the lab to the physiological response and performance of surfers in the water. Furthermore no studies have investigated how conditions such as wave size and wave period or the ability levels of surfers might affect the temporal and physiological parameters of the activity.

The work described in this chapter has two broad aims:

To investigate the relationships between wave size and wave period on the physiological demands such as the effects on heart rate, energy expenditure and exercise intensity during surfing.

To investigate the relationships between wave size and wave period on the performance parameters of surfing sessions. Such as the temporal distribution of activities, numbers of waves ridden, speed and distances of surfing sessions and individual rides.

5.2 Methodology

5.2.1 Participants

Following institutional ethical approval (Appendix 5.0) and obtaining informed consent participants underwent laboratory and field based assessments. In total n = 39 participants completed 60 surfing sessions for the performance analysis aspect of the study. A subset (n = 19) of participants underwent laboratory testing to facilitate the physiological analysis of 39 surfing sessions. All participants were rated using the Hutt et al. (2001) surfer skill rating (HSSR) as described in Chapters 1 and 2 to give an objective assessment of ability.

5.2.2 Laboratory procedures

Following the recording of resting heart rate, blood pressure was measured using a mercury sphygmanometer (Accosan, Dekomet, Harlow, UK) and stethoscope (Littman, Classic II S.E., Neuss, Germany). Cut off values for participation in the exercise test were a resting heart rate of 100 b.min-1 or higher, systolic blood pressure of 140 mmHg or above and a diastolic blood pressure of 90 mmHg as these values would indicate mild hypertension (ACSM 2013).

Height and body mass were measured using the methods previously described in section 2.2. Submaximal oxygen uptake, blood lactate response, and $\dot{V}O_{2max}$ were measured using an incremental exercise test performed by paddling in a prone position on a Vasa Ergometer (Vasa Inc, Essex town, Vermont, USA). The test began with the participant paddling at 30 watts for three minutes following which the participant was given a one minute rest period while a 400 µL fingertip capillary blood sample was taken which was then analysed for blood lactate concentration using a YSI2300 stat analyser (Analytical technologies, Farnborough, UK). Following the one minute rest period the exercise intensity was increased by 20 watts for three minutes before the next sample was taken. The test proceeded in this manner until a blood lactate sample of 4 mMol.L^{-1} (OBLA) or greater was measured. The participant was then allowed 10 minutes to recover before they returned to the ergometer to perform the $\dot{V}O_{2max}$ element of the test. The initial workload was set as 20 watts less than that which elicited OBLA and the participant paddled continuously, increasing their power output by 10 watts every minute until they reach volitional exhaustion or were unable to maintain the prescribed power output. Oxygen uptake was measured continuously throughout both aspects of the test via a face mask (Hans Rudolph, inc, USA.) using the Metalyzer 3B (Cortex Biophysik, GmbH, Leipzig, Germany) metabolic system. The system was calibrated every hour using a Hans Rudolph 3 litre calibration syringe for the volume transducer. The gas analysers were calibrated using both ambient air and a calibration gas (O2 18.23%, CO2 2.07%). The pressure sensor was calibrated using a digital barometer (Oregon Scientific). Heart rate was measured throughout using a Polar T31 chest strap (Polar Electro, Oy, Finland) through the Metalyser 3B.

Following completion of the laboratory exercise test the heart rate $\dot{V}O_2$ relationship was established through linear regression to predict the $\dot{V}O_2$ associated with heart rate during surfing. Energy expenditure was calculated using the $\dot{V}O_2$ derived from the heart rate assuming 5 kcal per litre of oxygen utilised (Mc Ardle et al. 2007). The heart rate, $\dot{V}O_2$ and blood lactate parameters were used to identify the heart rates associated with the exercise intensity zones of easy (below the lactate threshold), steady (above lactate threshold but below the lactate turn-point), tempo (above the lactate turn-point and up to the heart rate associated with 90% of $\dot{V}O_{2max}$) and the intermittent zone which is defined as within 10% of $\dot{V}O_{2max}$ (Jones 2001, Jones and Doust 2001). The correlation between the actual and predicted $\dot{V}O_2$ using the regression was r = 0.665 ($P < 0.01$) (Standard error of estimate 0.563).

5.2.3 On-water testing

The surfers were each equipped with a Polar RCX5 heart rate monitor and G3 GPS monitor (Polar Electro, Oy, Finland). This was used in conjunction with a T31 transmitter belt to allow for transmission of the heart rate signal through the seawater. The G3 GPS monitor was placed in a dry-bag (1 litre dry pouch, Overboard, Surrey, UK) due to its poor waterproofing properties and the heart rate monitor was also placed in the bag to reduce potential loss of signal. Recording of Heart rate and GPS position was initiated immediately before entry to the water and the dry pouch and its contents were then placed down the back of the participant's wetsuit between the shoulder blades to avoid causing additional discomfort. Surfers were asked to surf in a "normal" manner during their session. On exit from the water the dry pouches were removed from the back of the wetsuit and recording was stopped. The heart rate monitors were downloaded onto the Polar Precision 5 software to allow for scrutiny of the data. Any erroneous samples due to technical reasons such as values of zero for heart rate due to loss of signal were either corrected using the correction tool within the software or they were removed from the data set.

Using the GPS data the number of rides were recorded and converted into a per hour measurement by dividing the number of rides by the session time (seconds) and then multiplying by 3600. The analysis identified the maximum speed during each ride and the standard deviation of the maximum ride speeds for each session. The average, maximum, minimum and standard deviation of the ride times were calculated for each session. The average, maximum, minimum and standard deviation of the ride distances for each session was also calculated.

The perceived wave height was recorded as the estimated wave face height by the surfers. Perceived wave heights were generally given in feet as perceived relative to the surfer – head high ~ 6ft, waist high ~ 3ft, etc (see Chapter 1 for discussion regarding wave height description) by the surfers and then converted into metre units for analysis. Wave buoy measurements of wave height and wave period were taken from the national wave buoy data centre (http://www.ndbc.noaa.gov/maps/United_Kingdom.shtml), with station 62107 (the Seven Stones Lightship) providing much of the data for Devon and Cornwall sessions and station 62001 (the Gascogne Buoy) providing the data for the sessions in South West France. Where data were required retrospectively they were gathered from the historical data sets maintained by www.magicseaweed.com which can also provide predicted breaking wave heights for all of the locations.

5.2.4 Data analysis

The heart rate files were exported into Microsoft Excel 2010 (Microsoft corporation) as comma separated value (.csv) files. This was then imported into Matlab (Mathworks, Cambridge, United Kingdom) and an algorithm used to identify the percentage time spent in each of the training zones. The heart rate $\dot{V}O_2$ regression equation for each participant was used to predict total energy expenditure during the surfing session.

The GPS files were first converted from GPS exchange format (.gpx) to comma separated value files using the MapSource software (Garmin, Southampton, United Kingdom). The comma separated value files were then analysed using Matlab (R2012b). Using 1Hz sampling the velocities derived from the second by second difference of longitude and latitude allows the distance covered (m) to be calculated by multiplication of the speed ($m.s^{-1}$) by the time in seconds. A ride was identified when the speed of the surfer was greater than the minimum ride speed threshold of 2.5 m.s-1 for a minimum of 4 seconds. The rides were analysed using both of the minimum ride speeds and the most appropriate criteria chosen. This was done to minimise the interference of high speed paddling on the calculation of rides and to maximise the boundaries (start and finish point) of rides; this was performed on a subjective basis. Portions of data that were above the minimum wave speed threshold but lasted less than 4 seconds were discounted as waves and reported as miscellaneous; where the wave speed dropped below the minimum riding threshold for a period of less than 4 seconds the analysis removed the seconds of data and interpolated the data to allow the two (or more) discreet bouts to be counted as one wave. As a result there might have been some slight overestimation of distance travelled for the waves where minimum speed was interpolated as the distance covered are a result of speed and time. GPS can occasionally produce spurious data through losses in signal or through the surfer performing free falls or aerial manoeuvres. A maximum wave speed threshold was incorporated using theoretical max speed threshold for a surfer (Dally 2001):

$$\text{Max speed threshold} \approx 6.04 \sqrt{Hb} \quad \text{(eq.2)}$$

Where Hb is the breaker height as calculated by 1.29 x the significant wave height. Any data points that were in excess of 1.2 times of the max speed threshold were removed and interpolated using the data points immediately preceding and following the spurious point. The times when the surfers were travelling at less than 0.5 $m.s^{-1}$ were identified as "waiting" (there might be some movement due to local tides, wind or current). Surfers were identified as "paddling" when their speeds were in excess of the "waiting" threshold but below the minimum ride speed threshold. The totals of "riding", "waiting" and "paddling" were summed and any outstanding data was classified as "miscellaneous". The miscellaneous data would include those above the minimum speed threshold but lasting less than 4 seconds (sprint paddling, missed waves, wipe outs) and periods when data were lost due to submersion (potentially during duck-diving or wipe-outs). Percentages are given for time spent in each of these activities and the distance covered per hour both surfing and paddling are presented.

Analysis of the wave data allowed calculation of maximum, minimum, mean and standard deviation values for ride distances, speeds, and time. Total number of rides, total distance covered, total distances ridden, total and percentage time riding, total time and percentage time waiting, total time and percentage time paddling, total time and percentage time in miscellaneous were also calculated.

It should be noted that surfing sessions varied in duration but absolute values were converted to per hour values to allow for comparison.

5.2.5 Statistical analysis

Means and standard deviations were calculated for the physiological parameters i.e. time spent in each exercise zone, the ride parameters of ride time, distance, speed and performance parameters i.e. percentage of total time spent in each activity. Spearman`s rank correlations were used to determine the relationship for HSSR with wave conditions, physiological parameters, ride parameters and performance parameters. Pearson’s correlations were preformed between the wave parameters of perceived wave height, wave height and wave period with the physiological parameters, ride parameters, and performance parameters. These comparisons were also evaluated using partial correlations controlling for the HSSR of the participants to ensure that the wave conditions were the sole independent variables. All statistical analysis was performed in IBM SPSS statistics (v20).

5.4 Results

Table 5.1 shows the descriptive values for the whole sample of participants (n =39) who participated in surfing whilst wearing heart rate and GPS devices and the subset of participants (n =19) who also underwent laboratory assessment to facilitate physiological analysis of their recorded sessions.

Table 5.1 Sample and condition descriptors for physiological and performance analysis.

	Performance analysis Mean ± SD	Physiological analysis Mean ± SD
Sample size (n)	39	19
Stature (m)	1.77 ± 0.12	1.75 ± 0.15
Body mass (kg)	72.6 ± 9.9	72.1 ± 8.5
Age (years)	24.5 ± 6.3	26.5 ± 7.4
Surfer skill rating	5.2 ± 1.2	5.5 ± 1.3
$\dot{V}O_{2max}$ ($L.min^{-1}$)		2.6 ± 0.5
$\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)		35.9 ± 6.1
Perceived wave height (m)	1.0 ± 0.4	1.1 ± 0.4
Wave height (m)	1.5 ± 0.8	1.5 ± 0.7
Wave period (s)	9.2 ± 1.6	9.4 ± 1.7
Total number of surf sessions analysed	60	39

Table 5.2 gives the physiological parameters measured during 39 surfing sessions of the participants underwent laboratory testing (N=19). The average heart rate was 146 b.min-1 which equated to 80.30% of the maximum heart rate measured during the laboratory testing.

Table 5.2 Physiological parameters of surfing performance.

	Mean ± SD
Average heart rate ($b.min^{-1}$)	146.4 ± 16.8
Average heart rate as percentage of maximum of laboratory test	80.3 ± 7.6
Percentage of time in “easy” zone	19.8 ± 19.2
Percentage of time in “steady” zone	34.0 ± 22.0
Percentage of time in “tempo” zone	34.0 ± 22.3
Percentage of time in “intermittent” zone	12.4 ± 15.6
Energy expenditure ($kcal.h^{-1}$)	493.0 ± 231.7

Table 5.3 gives the ride parameters of the whole sample of sixty surf sessions. The values were derived from the GPS data and provide an overview of the speed, time and distance characteristics of the surfer's rides.

Table 5.3 Ride parameters of surfing.

	Mean ± SD
Number of Rides (per hour)	20.6 ± 11.4
Maximum of ride speeds (m.s-^{1})	6.1 ± 1.2
Stdev of Maximum of ride speeds (m.s^{-1})	1.1 ± 0.5
Mean ride time (s)	13.0 ± 5.0
Maximum ride time (s)	27.3 ± 13.3
Minimum ride time (s)	4.7 ± 1.5
Stdev of the ride times (s)	7.3 ± 4.2
Mean ride distance (m)	54.8 ± 25.4
Maximum ride distance (m)	117.7 ± 63.4
Minimum ride distance (m)	16.5 ± 7.3
Stdev of ride distances (m)	32.0 ± 18.8

Table 5.4 shows the performance parameters for the surfing sessions. This includes a breakdown of the session into the percentage of time spent in each activity and the absolute amount of time spent in each activity. It is possible to identify that the majority of the surfing session are spent paddling and waiting whilst actual on average riding contributes only 8.1% of the total time.

Table 5.4 performance parameters during surfing.

	Mean ± SD
Total distance covered whilst surfing (%)	25.6 ± 9.6
Total time spent waiting (%)	41.8 ± 9.8
Total time spent paddling (%)	47.0 ± 6.1
Total time spent riding (%)	8.1 ± 5.3
Total time miscellaneous (%)	3.1 ± 1.9
Total time spent waiting per hour (s)	1452.9 ± 440.7
Total time spent paddling per hour (s)	1636.6 ± 374.8
Total time spent riding per hour (s)	282.6 ± 195.2
Total time spent miscellaneous per hour (s)	107.9 ± 69.2
Distance covered whilst surfing (m.hour^{-1})	891.4 ± 378.9
Total distance per hour (m)	3925.5 ± 1239.8
Average speed (m.s^{-1})	4.2 ± 1.1

The results displayed in Table 5.5 show that there is a significant relationship between the Hutt rating of surfer skill and the perceived wave height of the conditions measured during the course of this study. This result shows that the participants with the higher HSSR tended to surf in larger waves. The effect of this correlation should be considered when analysing the effect of to the wave conditions and as such the following tables present partial correlations controlling for HSSR allowing the influence of wave conditions on the physiological response, ride parameter and performance parameters to be assessed independently of the ability of the surfers.

Table 5.5 Spearman's rank coefficients between skill and wave condition variables.

	Perceived wave height (m)	Wave height (m)	Period (s)
HSSR	$r_s = 0.349$**	$r_s = -0.019$	$r_s = 0.249$

*****correlation significant at $P < 0.05$, **correlation significant at $P < 0.01$.

The results presented in Table 5.6 show that there were significant relationships between the Hutt rating of surfer skill and some physiological measure. Significant negative relationships exist between the average heart rate as a percentage of the maximum laboratory heart rate ($r_s = -0.412$, $P < 0.01$) and the percentage of time in the "intermittent" zone ($r_s = -0.483$, $P < 0.01$). Suggesting that as surfer ability increases these values decrease during surfing. There was a significant relationship between the Hutt rating of surfer skill and the percentage of time in the "steady" zone ($r_s = 0.435$, $P < 0.01$). There exists a negative relationship between the perceived wave height and the energy expenditure of the surfers ($r_s = -0.416$, $P < 0.01$). When controlling for the Hutt rating of the surfers the correlation remains significant (r_p = -0.351, $P < 0.05$). There were no significant relationships between the wave height and the physiological parameters but the percentage time in the "easy" zone was significantly correlated to wave period ($r_S = 0.405$, $P < 0.01$), when controlling for the ability of the surfers the partial correlation was significant ($r_p = -0.408$, $P < 0.05$). The smallest significant coefficient of determination was 10% for the relationship between average heart rate and the wave period. The largest significant coefficient of determination was 24% for the relationship between average heart rate and the wave period when corrected for HSSR.

Table 5.6 Correlations between HSSR, perceived wave height, wave height, wave period and physiological indices; partial correlations corrected for HSSR.

	Hutt rating	**Perceived wave height (m)**		**Wave height (m)**		**Wave period (s)**	
	Spearman's rho	**Spearman's rho**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**
Average HR (beats.min^{-1})	r_s = -0.248	r_s = -0.029	r_p = -0.101	r = -0.107	r_p = -0.133	r = 0.120	r_p = 0.310
Average % HR Max	r_s = -0.412**	r_s = -0.151	r_p = -0.193	r = -0.054	r_p = -0.253	r = 0.312*	r_p = 0.490**
% time "Easy"	r_s = -0.058	r_s = -0.017	r_p = 0.800	r = 0.224	r_p = -0.223	r = -0.405*	r_p = -0.408**
% time "Steady"	r_s = 0.435**	r_s = 0.174	r_p = 0.130	r = 0.001	r_p = -0.053	r = 0.002	r_p = -0.072
% time "Tempo"	r_s = -0.136	r_s = 0.006	r_p = -0.009	r = -0.118	r_p = -0.140	r = 0.280	r_p = 0.316
% time "Intermittent"	r_s = -0.483**	r_s = -0.291	r_p = -0.234	r = -0.097	r_p = -0.192	r = -0.097	r_p = 0.173
Energy Expenditure (Kcal.HR^{-1})	r_s = -0.123	r_s = -0.416**	r_p = -0.351*	r = 0.047	r_p = 0.083	r = 0.087	r_p = -0.263

***correlation significant at P < 0.05, **correlation significant at P < 0.01

Table 5.7 gives the correlations between the ride parameters and HSSR, perceived wave height, wave height, wave period and ride parameters; partial correlations are corrected for HSSR. The number of rides per hour was found to be significantly correlated with the perceived wave height (r_s = -0.262, $P < 0.05$). Maximum ride speed was found to have a significant ($P < 0.01$) positive relationship to HSSR, the perceived wave height, perceived wave height accounting for surfer skill rating, wave height, wave height controlling for surfer skill rating, and the wave period accounting for surfer skill rating. The standard deviation of the maximum ride speeds was significantly ($P < 0.01$) related to the perceived wave height, perceived wave height controlling for HSSR, wave height and the wave height controlling for the HSSR. Mean ride time was found to be significantly ($P < 0.01$) related to perceived wave height and perceived wave height controlling for HSSR. Significant but weaker ($P < 0.05$) relationships were found for mean ride time with wave period and wave period controlling for HSSR; and for maximum ride time with perceived wave height controlling for HSSR and the wave period. The smallest significant coefficient of determination was 7% for the relationship between the number of rides per hour and the perceived wave height. The largest significant coefficient of determination was 75% for the relationship between maximum ride speed and the perceived wave height when corrected for HSSR.

Table 5.7 Correlations between HSSR, perceived wave height, wave height, wave period and ride parameters; partial correlations are corrected for HSSR.

	Hutt rating.	Perceived wave height (m)		Wave height (m)		Wave period (s)	
	Spearman's rho	Spearman's rho	Partial correlation	Pearson`s correlation	Partial correlation	Pearson`s correlation	Partial correlation
Number of Rides (per hour)	r_s = -0.167	r_s = -0.262*	r_p = -0.102	r = 0.166	r_p = 0.175	r = -0.192	r_p = -0.165
Maximum of ride speeds ($m.s^{-1}$)	r_s = 0.454**	r_s = 0.707**	r_p = 0.866**	r = 0.464**	r_p = 0.510**	r = 0.236	r_p = 0.371**
Stdev of Maximum of ride speeds ($m.s^{-1}$)	r_s = 0.181	r_s = 0.500**	r_p = 0.654**	r = 0.484**	r_p = 0.415**	r = 0.009	r_p = 0.221
Mean ride time (s)	r_s = 0.193	r_s = 0.463**	r_p = 0.354**	r = 0.231	r_p = 0.228	r = 0.322*	r_p = 0.283*
Maximum ride time (s)	r_s = 0.175	r_s = 0.362	r_p = 0.296*	r = 0.204	r_p = 0.199	r = 0.271*	r_p = 0.236
Minimum ride time (s)	r_s = 0.000	r_s = 0.070	r_p = 0.128	r = 0.199	r_p = 0.200	r = 0.027	r_p = 0.033

*correlation significant at P < 0.05, **correlation significant at P < 0.01.

Table 5.8 presents the correlations between HSSR, perceived wave height, wave height, wave period and ride parameters; partial correlations are corrected for HSSR. The standard deviation of the ride time was found to be significantly related to the perceived wave height when controlling for Hutt surfer skill ability rating ($P < 0.01$) with weaker but significant relationships ($P < 0.05$) with wave height and the wave height controlling for HSSR. The mean ride distance was significantly ($P < 0.01$) related perceived wave height when controlling for HSSR and weaker but significant relationships were found ($P < 0.05$) for Hutt rating, perceived wave height and wave period. The maximum ride distance was found to be significantly ($P < 0.05$) related to perceived wave height, perceived wave height when controlling for HSSR, wave period and wave period when controlling for HSSR. Minimum ride distance was found to be significantly ($P < 0.05$) related to the perceived wave height and the wave height when controlling for HSSR. The standard deviation of the ride distances was found to be significantly ($P < 0.01$) related to the perceived wave height when controlling for HSSR, and the wave period. Weaker but significant correlations ($P < 0.05$) were found with the HSSR of the participants and the wave period when controlling for HSSR. The smallest significant coefficient of determination was 7% for the standard deviation of the ride distances and HSSR. The largest significant coefficient of determination was 23% for the relationship between the maximum ride distance and the perceived wave height.

Table 5.8 Correlations between HSSR, perceived wave height, wave height, wave period and ride parameters; partial correlations are corrected for HSSR.

	Hutt rating	Perceived wave height (m)		Wave height (m)		Wave period (s)	
	Spearman's rho	**Spearman's rho**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**
Stdev of the ride times (s)	$r_s = 0.103$	$r_s = 0.411$	$r_p = 0.344$**	$r = 0.304$*	$r_p = 0.301$*	$r = 0.261$	$r_p = 0.233$
Mean ride distance (m)	$r_s = 0.392$*	$r_s = 0.601$*	$r_p = 0.398$**	$r = 0.202$	$r_p = 0.202$	$r = 0.307$*	$r_p = 0.245$
Maximum ride distance (m)	$r_s = 0.317$	$r_s = 0.484$*	$r_p = 0.318$*	$r = 0.142$	$r_p = 0.136$	$r = 0.333$*	$r_p = 0.279$*
Minimum ride distance (m)	$r_s = 0.220$	$r_s = 0.300$*	$r_p = 0.235$	$r = 0.271$	$r_p = 0.268$*	$r = 0.003$	$r_p = -0.028$
Stdev of ride distances (m)	$r_s = 0.264$*	$r_s = 0.528$	$r_p = 0.362$**	$r = 0.226$	$r_p = 0.224$	$r = 0.369$**	$r_p = 0.325$*

*correlation significant at $P < 0.05$, **correlation significant at $P < 0.01$.

Table 5.9 shows the correlations between HSSR, perceived wave height, wave height, wave period and performance parameters; partial correlations corrected for HSSR. Significant relationships ($P < 0.05$) were found between the percentage of the total session distance riding and the Hutt rating of the participants, perceived wave height, wave height and the wave height when controlling for HSSR. Percentage of total time spent waiting was negatively correlated with wave height and the wave height when controlling for HSSR. Percentage time spent paddling was significantly related ($P < 0.01$) to the HSSR of the participants. The percentage of the total time spent riding was significantly ($P < 0.01$) related to the wave height and the wave height when controlling for HSSR. The percentage of total time in miscellaneous activities was significantly ($P < 0.01$) correlated with the perceived wave height when controlling for HSSR, wave height and the wave height when controlling for HSSR; A significant ($P < 0.05$) but negative relationship was found with HSSR. The smallest significant coefficient of determination was 7% for the relationship between percentage of total distance riding and HSSR. The largest significant coefficient of determination was 22% for the relationship between percentage of time in miscellaneous activities and the wave height when corrected for HSSR.

Table 5.9 Correlations between HSSR, perceived wave height, wave height, wave period and performance parameters; partial correlations corrected for HSSR.

	Hutt rating	Perceived wave height (m)		Wave height (m)		Wave period (s)	
	Spearman's rho	**Spearman's rho**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**
% Total distance riding	$r_s = 0.267$*	$r_s = 0.280$*	$r_p = 0.231$	$r = 0.313$*	$r_p = 0.310$*	$r = 0.076$	$r_p = 0.035$
% time waiting	$r_s = -0.188$	$r_s = -0.146$	$r_p = -0.200$	$r = -0.275$*	$r_p = -0.272$*	$r = -0.107$	$r_p = -0.082$
% time paddling	$r_s = 0.364$**	$r_s = 0.117$	$r_p = -0.017$	$r = -0.44$	$r_p = -0.058$	$r = 0.099$	$r_p = 0.038$
% time riding	$r_s = 0.046$	$r_s = 0.062$	$r_p = 0.227$	$r = 0.394$**	$r_p = 0.396$**	$r = 0.027$	$r_p = 0.036$
% time misc`	$r_s = -0.299$*	$r_s = 0.180$	$r_p = 0.452$**	$r = 0.452$**	$r_p = 0.471$**	$r = 0.016$	$r_p = 0.211$

*correlation significant at $P < 0.05$, **correlation significant at $P < 0.01$.

Table 5.10 gives the correlations between HSSR, perceived wave height, wave height, wave period and performance parameters; partial are correlations corrected for HSSR. Total riding distance was significantly related (P < 0.05) to HSSR, perceived wave height and wave height when controlling for HSSR. A more significant correlation (P < 0.01) was found with wave height. The total distance per hour was found to be significantly related (P < 0.01) to wave height and wave height controlling for HSSR, a significant but weaker significant correlation (P < 0.05) was also found with the perceived wave height when controlling for HSSR. The average speed during the session was found to be significantly (P < 0.01) related to HSSR. The smallest significant coefficient of determination was 16% for the relationship between total distance riding and HSSR. The largest significant coefficient of determination was 18% for the relationship between average speed and HSSR.

Table 5.10 Correlations between HSSR, perceived wave height, wave height, wave period and performance parameters; partial correlations are corrected for HSSR**.**

	Hutt rating	Perceived wave height (m)		Wave height (m)		Wave period (s)	
	Spearman's rho	**Spearman's rho**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**	**Pearson`s correlation**	**Partial correlation**
Total distance riding ($m.HR^{-1}$)	$r_s = 0.267$*	$r_s = 0.280$*	$r_p = 0.231$	$r = 0.313$**	$r_p = 0.310$*	$r = 0.076$	$r_p = 0.035$
Total distance per hour (m)	$r_s = 0.144$	$r_s = 0.225$	$r_p = 0.334$*	$r = 0.343$**	$r_p = 0.427$**	$r = 0.094$	$r_p = 0.081$
Average speed ($m.s^{-1}$)	$r_s = 0.428$**	$r_s = 0.295$	$r_p = 0.125$	$r = -0.006$	$r_p = -0.024$	$r = 0.240$	$r_p = 0.174$

*****correlation significant at $P<0.05$, **correlation significant at $P<0.01$.

Figure 5.1 shows an example of a GPS track of a participant in this session the participant caught a total of 41 waves, travelled a total distance of 7.1Km with the total distance of their rides as 1.9Km.

Figure 5.1 Example GPS track of participant

5.5 Discussion

5.5.1 Participants and conditions

Data analysis shows that the sample of participants here (Table 5.2) were of similar stature, body mass and age to those reported in the wider literature (Lowdon 1989, Mendez-Villanueva *et al.* 2005, Farley *et al.* 2011). However the average ability of the surfers in this sample can be described as skill rating 5 or “surfers able to execute standard manoeuvres consecutively on a single wave” (Hutt *et al.* 2001) and thus are generally lower in ability than in those studies that have utilised professional or competitive surfers (Lowdon 1980, Lowdon and Pateman 1980, Lowdon 1983, Mendez-Villanueva and Bishop 2005, Mendez-Villanueva *et al.* 2005, Mendez-Villanueva *et al.* 2006, Farley *et al.* 2011, Farley *et al.* 2012). It should be noted however that the current sample included a range of surfers from level 2 HSSR who are "learner surfers able to successfully ride laterally along the crest of a wave" to level 8 "professional surfers, able to consecutively execute advanced manoeuvres" (Hutt *et al.* 2001). The perceived wave height during the study averaged to approximately 1.0 metre which would be described by surfers as approximately 3 feet or as waist to chest high. The perceived wave height is slightly higher at 1.5 metres the differences between the observed perceived wave height and the wave height measured by the wave buoy might be reflective of differences in offshore waves and those that break on the beach having interacted with the local bathymetry. Another possible explanation for the differences in measured and reported wave sizes might be that surfers were attempting to optimise their surfing experience by maximising the appropriateness of local weather conditions. In this vein, swells that are accompanied by south west winds, which are predominant in the South West of England, will lead to surfers seeking shelter from the wind or beaches that will orientate the wind off-shore and thus will more likely produce plunging waves (Butt and Russell 2006). In doing so surfers might actually be surfing locations that are not in the direct line of swell or in a swell shadow where waves are refracting into the surf zone. Thus the size of the waves surfed might be smaller than those measured by the wave buoy.

5.5.2 Physiological responses

The average heart rate during surfing in the current study was almost identical to the values reported by Mendez-Villanueva and Bishop (2005) for surfers in simulated competitive heats and comparable to the average heart rates reported during competition by Farley *et al.* (2012) and during 1 hour of surfing by Meir *et al.* (1991). The average heart rate during surfing as a percentage of the maximum heart rate during the laboratory test was also comparable to the values reported in previous studies, being slightly greater than the values reported by Farley *et al.* (2012) and Meir *et al.* (1991) but 5% lower than the values of Mendez-Villanueva and Bishop (2005). Thus far no study has reported heart rate zones during surfing, with respect to blood lactate profiles measured through laboratory testing. Surfers were found to spend 19.9% of the time in the "easy" zone which is defined as work rates below the lactate threshold and can be considered as the moderate exercise domain; where exercise can be maintained for extended periods of time (Jones and Doust 2001) . Mendez-Villanueva and Bishop (2005) reported a similar amount of time (20%) spent as less than 75% of maximum heart, suggesting this might represent portions of activity where the surfers are resting during waiting and between bouts of paddling. The percentage of time in the "steady" zone is defined as exercise above the lactate threshold but below the lactate turn point. This is an approximation of the heavy domain of exercise which, if performed constantly can be maintained for 40 to 60 minutes (Jones and Doust 2001). The upper boundary of the steady zone is defined by the lactate turn-point, and 33.9% of the total time was spent in this zone. This supports the strong relationships between blood lactate parameters measured in the laboratory and the performance levels of surfers (Mendez-Villanueva *et al.* 2005). Furthermore Snyder *et al.* (2008) identified that the maximum lactate steady state can be approximated to 85% of maximum heart rate which compares well to the average heart rate reported in published literature (Meir *et al.* 1991, Farley *et al.* 2012) and in the current study, with surfers working less than 5% of the total time surfing in this zone. The intermittent zone is associated with heart rates within 10% of the heart rate eliciting $\dot{V}O_{2peak}$. Surfers in the current study performed for 12.4% of the total time in this zone supporting previous studies showing that surfing consists of mainly moderate to heavy exercise, utilising aerobic metabolism interspersed with high intensity exercise. This requires both aerobic and anaerobic elements and that surfing meets the American College of Sports Medicine training intensity criteria for developing and maintaining cardio-respiratory fitness in healthy adults (Meir *et al.* 1991, Pollock *et al.* 1998, Farley *et al.* 2012). The hourly energy expenditure in the current study of 493 kcal is similar to the values reported by Meir *et al.* (1991) who found hourly energy expenditure of 496.41 kcal (2077KJ).

5.5.3 Ride parameters

The number of rides identified as 20.6 rides per hour is significantly higher than the value of 5 rides during a 25 minute heat (12 rides per hour) as recorded by Mendez-Villanueva *et al.* (2006) but is similar to the 7 rides during a 20 minute heat (21 rides per hour), reported by Farley *et al.* (2012). These differences might be due to the surfers in the Mendez-Villanueva *et al*. (2006) study making tactical decisions to ensure that they achieved the highest possible score from their two scoring waves within the wave limit set within competition (ASP 2013). Alternatively it might be due to differences in the definition of wave riding; Mendez-Villanueva *et al*. (2006) and Farley *et al.* (2012) recorded riding as the time from the last arm stroke to the moment the subject's feet lost contact with the board. However it is not clear how the investigators dealt with non-rides where the surfer takes off accelerating down the wave but does not get to their feet or when the surfer falls on take-off and as such the definition of riding is somewhat subjective and might lead to variations in the number of waves counted when using this method. The method used in the current study is objectively driven in that it is defined by the discreet strings of data where the surfer was travelling above the wave threshold for a period of four seconds or more. The reader must be aware that the number of waves included in this measurement will include an undefined number of instances whereby subjective assessment of the ride would have been deemed as a “non-ride”. It is expected that as the level of ability of the surfer increases the number of “non-rides” will decrease and thus the reliability of the measure will increase. Additionally very short rides where surfers might get to their feet for a very short period (less than 4 seconds) of time before falling or “pulling out” might be subjectively classed as a ride but would not be recognised as such in the current method. The similarities in results presented here with those in the published literature (Mendez-Villanueva *et al.* 2006, Farley *et al.* 2012) support the use of the current methodology as a method of surfing performance analysis.

The maximum ride speed was measured as the mean maximum ride speed over all of the maximum speeds from each surf session, this measured 6.1 $m.s^{-1}$ and is considerably slower than the average maximum speed reported by Farley *et al.* (2012) of 33.4 $km.h^{-1}$ (9.3 $m.s^{-1}$). Differences might be due to the variations in the ability of the surfers in the current study in comparison to the participants of the Farley *et al.* (2012) study, who were all described as nationally ranked surfers and as such would be rated as 7 or above on the HSSR. Farley *et al.* (2012) also reported that the wave height during their study was 4ft (1.2m) and using maximal sustainable speed calculation (Dally 2001) this would give a maximal sustainable speed of 9.63 $m.s^{-1}$ in those conditions. It is unclear whether the surfers in the Farley *et al.* (2012) study were surfing faster as a function of the wave height, the higher ability of the surfers or whether any unrealistically high wave speeds due to technological factors were not removed the Farley *et al.* (2012) data set, resulting in a higher average maximum speed. The intra-surf standard deviation of maximum ride speeds was found to be 1.1 $m.s^{-1}$ suggesting that there was approximately 17% variation in the maximum ride speeds during each session. The mean ride time of the current study (13 seconds) was slightly longer than the values reported by Mendez-Villanueva *et al.* (2006) who found mean ride times of 11.6 seconds but similar to the 14.9 ± 5.6 values reported by Farley *et al*. (2012) suggesting that these values are within the normal range of ride times. The maximum ride times of the current study were found to be 27.31 seconds which is considerably higher than the data presented by Mendez-Villanueva et al. (2006). The long maximum ride distances presented in the current study might have been influenced by the in configuring the interpretation of the GPS so that data differentiate between riding and non riding. Often surfers will end a surfing session by riding a wave and then dropping to the prone position once the wave has broken and then riding that broken wave to the shoreline; using the algorithm employed in the current study the total distance of this activity would be classsed as one ride and might have had a slight influence on the final data. The minimum ride time found in the current study was 4.71 seconds. This value is slightly lower than the 6 seconds minimum ride time reported by Mendez-Villanueva et al. (2006). The minimum wave speed reported by Mendez-Villanueva et al. (2006) supports the use of the criteria in the algorithm presented here that dictates the ride speed must be above the threshold speed for 4 seconds before being counted as a wave, thus possibly achieving a minimum ride time that would be below the minimum values reported in the other studies. It is worth considering that the minimum ride time values published in the literature are likely to be affected to the subjective way in which a ride has been classified by the investigators; specifically the determination as to the points at which a rides begin and end. The standard deviation of the ride times and ride distances represent the variability in the ride times within each surfing session. These are discussed in further detail in Section 5.5.5.

Thus far no other study has reported the distance parameters of individual rides within a surfing session although Farley *et al.* (2012) did produce values for total distance of the session. It would be expected that the ride distances could be affected by the surf conditions and the location with point breaks offering the maximal ride distances. The majority of the sessions included in the present study were performed at beach breaks or at reef breaks that might offer a more intense ride but not necessarily longer rides (Butt and Russell 2006).

5.5.4 Performance parameters

We can see that actual riding accounts for 25.6% of the total distance accrued during the surf session with the remainder being explained through paddling and drifting due to currents. Farley *et al.* (2012) observed that after completing a ride of approximately 30 seconds the surfers would need to paddle and duck dive seawards for approximately 3 minutes to get “out back” beyond the breaking waves and then would need to paddle for an additional 40-50 seconds parallel to the beach to reach the take - off point.

The percentage of the total time spent waiting was found to be 41.8% (1452.9 S.hr^{1}) and this is in line with time spent waiting reported in the literature which ranges from 28% (Farley *et al.* 2012) to 42% (Mendez-Villanueva *et al.* 2006). The value identified in the current study is based on a speed threshold and as single arm paddling, or sculling to maintain position might be included in this value and might have been classified as paddling in other studies. The total time spent paddling in the current study was found to be 47.0% (1636. S.hr^{-1}) which aligns with values presented in the literature which vary from 35% (Meir *et al.* 1991) to 54% (Farley *et al.* 2012). The percentage amount of time riding in the current study was found to be 8.12% (282.6 S.hr^{-1}) compared with 3.8% of Mendez-Villanueva *et al.* (2006) and 8% with Farley *et al.* (2012). The percentage time recorded for miscellaneous activities was 3.1% (107.9 S.hr^{-1}), similar to the 2.5% and 5% values presented by Mendez-Villanueva et al (1991) and Farley *et al* (2012) respectively. These values are substantially smaller than the values presented by Meir *et al* (1991) who found that 16% of total time was spent performing miscellaneous activities.

The data presented in this study, using GPS as a method of measuring the activity profile of surfers, has found values that are comparable to those in the literature and supports the use of this method for future objective assessment of surfing activity. Using this method the percentage time spent in each activity can be described as

41.6%, 47.0%, 8.1% and 3.1% for waiting, paddling, riding and miscellaneous activities respectively.

5.5.5 Relationships between surfer skill, wave characteristics and measured physiological, ride and performance parameters

Thus far no study has reported how surfing ability or wave conditions might affect surfing performance or the distribution of activities during surfing. Table 5.5 gives the relationship between HSSR and the measures of wave conditions during the study. A significant relationship was found between HSSR and the perceived wave height and as similar correlations were not found with the wave height and period measured through the off-shore wave buoy it can be determined that in comparison to those of lower ability the better surfers were seeking and riding comparatively larger waves breaking on the beach for a given wave size measured at the off-shore wave buoy. Thus it can be concluded that when considering the effect of wave size on the parameters of surfing activity, ability should be taken into consideration.

Table 5.6 shows that the HSSR was significantly and negatively related to the average heart rate as a percentage of the maximum measured in the laboratory. This suggests that the better surfers work at a lower intensity than those who are less adept. This is supported by the significant relationship between HSSR and the percentage of time in the “steady” zone; and the significant negative relationship with the percentage of time in the “intermittent” zone this suggests that the better surfers spend a greater proportion of time in their “steady” zone than the less able surfers and less time in the “intermittent” zone than the less able surfers.

A significant negative relationship was found between total energy expenditure and perceived wave height and perceived wave height when controlling for HSSR, suggesting that as the wave height increases then total energy expenditure decreases. The explanation for this relationship might lie in the significant negative relationship between perceived wave height and the number of rides (Table 5.7). Therefore, it appears that as wave height increases then the number of waves ridden decreases.

Further analysis identified a strong significant relationship between the number of waves ridden and the energy expenditure of the surfers. (Farley *et al.* (2012)) noted that the highest heart rates were observed a few seconds following the completion of a ride and as such it was the demands of riding that were responsible for high heart rates. The decreased number of waves ridden would lead to decreased instances of high heart rates and decreased bouts of paddling where the surfers are returning to the line-up after catching a wave thus decreasing the associated energy expenditure. The wave period was found to be significantly correlated to the average heart rate, as a percentage of the maximum measured in the laboratory both generally and when controlling for HSSR. This suggests that as wave period increases the average heart rate increases. This is reflected in the significant negative relationships that are seen with the percentage time in the “easy zone” as wave period increases.

The relationship of maximum ride speed with ability demonstrates that the better surfers are able to utilise more speed from the wave, but generally as wave size increases then so does the maximum ride speed. This relationship is to be expected, considering the maximum theoretical ride speed has been shown to be a function of wave size (Dally, 2001). The perceived wave height is a function of both the wave height as measured from the wave buoy, the period of the wave and the interaction of these variables with the local bathymetry. The absence of any statistically significant relationships between wave period and the maximum ride speed, when ability is unaccounted for, might be the result of the higher rated surfers not only possessing superior ability but also superior “surf knowledge”. As such the more advanced surfers might be able to optimise their choice of surfing location for the given conditions to ensure the maximum wave height for a wave of a given (wave buoy) height and period and thus enhancing the achievable maximum theoretical wave speed during their sessions.

The standard deviation of the maximum ride speeds was found to be significantly related to the perceived wave height and the wave height measured using the wave buoy. As already mentioned the maximum theoretical ride speed is a function of wave height and as such when the wave height increases the potential maximum speed will also increase. Thus there is potential for greater variability as the wave size increases. The mean ride time was found to be significantly related to the perceived wave height and the wave period. Similar significant relationships (Table 5.8) were found for the mean ride distance suggesting that as the perceived wave height or period increase then the length of the mean amount of time riding and the mean distance travelled whilst riding will also increase. The relationship between maximum ride time and perceived wave height was significant when HSSR was controlled and the wave period was also found to be significantly related to maximum ride time, suggesting that increases in perceived wave height and the wave period are related to increased maximal length of time riding.

The minimum ride distance was significantly correlated with perceived wave height and also the wave height when controlling for HSSR. The standard deviation of the ride distances was found to be significantly related to HSSR, the perceived wave height when controlling for HSSR, the wave height when controlling for HSSR, the wave period and the wave period when controlling for HSSR. This increased variation in the ride distances will most likely be caused by and related to the increases in ride speed and ride time. A broad synopsis of these findings would suggest that as the size of the wave increases, in terms of perceived wave height, or the swell being recorded via the wave buoys and or the wave period increases, the ride speeds, distances, time duration, and the variation of these measures for each ride also increases.

The percentage times spent in the activities of waiting, paddling, riding and miscellaneous can be considered as composites of the individual ride parameters and sessional parameters such as total time and distance travelled. The values recorded during this study have been found to be comparable with the values reported in previous studies (Mendez-Villanueva *et al.* 2006, Farley *et al.* 2012). However significant relationships have been found that might influence the time spent in each of these activities (Table 5.9). The significant relationships with HSSR suggest that surfers with higher ratings of ability will have higher proportions of their total surfing distance accounted for by ride distance and that they will spend comparatively more time paddling perhaps to maximise their wave count. This also might result in the greater total distance travelled and higher average speed during the session (Table 5.10)

The higher the level of ability the lower the percentage of time spent in miscellaneous activities and thus the surfers are spending less time unsuccessfully paddling for waves, wiping out or choosing waves that are closing out and therefore presenting short rides (<4sec). This relationship could possibly explain the differences between the studies of Meir *et al.* (1991) who used recreational surfers and the studies of Farley *et al* (2012) and Mendez-Vallanueva (2005) who used competitive surfers.

There was a significant relationship between perceived wave height and the percentage of time in miscellaneous activities when controlling for surfing ability, suggesting across the range of ability of the participants in this study that, as wave height increases, so does the number of aborted or failed rides. The wave height, as measured from the wave buoy, is the most reliable method of assessing the waves that are available for the utilisation of surfers, and the perceived wave height might be an indication of how the surfers have utilised these conditions.

As the wave height increases there is a concomitant increase in the percentage of the mean ride distance, percentage time riding, total riding distance, total overall distance and percentage of time in miscellaneous activities, but the percentage of time spent waiting decreases. It is unclear how these relationships might have impacted the differences in previous studies as generally wave sizes have not been reported but Farley *et al* (2012) reported that the wave sizes during their study were consistently larger (1-1.5 m) than the current study (1.0 m) and the surfers in that study spent less time waiting, more time involved in miscellaneous activities, and covered comparatively greater distances; all of which would be supportive of the present findings.

5.6 Conclusions

This study has identified heart rate profile, energy expenditure and categorised the percentage time spent in the training zones of easy, steady, tempo and in Intermittent as determined by the blood lactate and heart rate profile of the surfers; during recreational surfing (Table 5.2). The study has determined by GPS analysis the performance parameters of surfing with respect to percentage time waiting, paddling, riding and miscellaneous activities. The performance parameter values of surfing activity derived through GPS in this study are congruent with the values published through the use of video analysis in the existing literature supporting the use of the GPS based method of this study.

This study has found that the ability levels of surfers, the wave size and period influence the physiological, ride and performance parameters during surfing. As ability levels of the surfers increase there is a reduction in the relative (metabolic) intensity and time spent in miscellaneous activities, but increases in the proportion of time spent in the steady zone, time spent paddling, riding and increases in both the speed and distance of rides. In relation to the wave characteristics as wave size increases there is a reduction in the total energy expenditure, number of rides, the proportion of time waiting but increases in the ride speed, ride distances, the variation in ride speed and distance, the proportion of total time riding, the proportion of time in miscellaneous activities and the total distance covered in the session. As wave period increases there is a decrease in the proportion of time spent in the “Easy zone”, with increase in the average heart rate and increases in maximum ride speed, time and distance. Thus far no other study has investigated these relationships.

Future studies on surfing performance should report the conditions in which the study is performed and author’s should recognise the effect of changes in surf conditions on the response of the surfers.

5.7 Future research possibilities

Potential for future studies exist in making direct comparisons between the GPS method and video analysis. This will allow for further scrutiny of the speed thresholds utilised in the analysis. The data contained here relate to recreational surfing with recreational surfers; future research opportunities lie in the measurement of top level competitive surfers during competition. The measurements utilised in this analysis could be used to compare performances at a given surf location but with recordings of wave height, period, wind direction and point of tide to give specific analysis of the demands of that location. This would be of particular interest for high profile locations utilised during the Association of Surfing Professionals world tour

Chapter 6.0 Concluding discussion and key findings

The literature describes the physiological profiles of surfers and the physiological demands of surfing, but this thesis evolves the corpus of knowledge by firstly seeking to confirm or refute the findings of earlier research relating to physiological characteristics of surfers and the demands of surfing using populations of surfers previously un-investigated. Secondly the research described in this thesis considers how physiological and environmental factors might affect the physiological and performance characteristics of surfing. This has not previously been attempted at any authoritative level.

This thesis summarised the body of knowledge relating to the exercise physiology of surfing and the environmental conditions that are necessary to create surfing waves in chapter 1. It was identified that the nature of exercise physiology of surfing has been largely focussed on describing the physiological characteristics of surfers (Lowdon 1980, Lowdon and Pateman 1980, Lowdon 1983, Mendez-Villanueva *et al.* 2005, Eurich *et al.* (2010), Farley *et al.* 2011, Sheppard *et al.* 2012), the physiological demand of surfing activity in competitive or recreational settings (Meir *et al.* 1991, Mendez-Villanueva *et al.* 2006, Farley *et al.* 2012) and issues relating to the technicalities of surfing competition (Lowden *et al.* 1996, Mendez-Villanueva *et al.* 2010).

Chapter 2.0 investigated the anthropometric variables of surfers and their relationship to performance and ability in male surfers. Lowdon (1980) Investigated the fitness requirements of surfers and in the process of this work evaluated the body composition of 76 male surfers who competed in the Bells Beach surf championship. As such the participants in Lowdon (1980) study would have been classed at level 7 using the HSSR (Hutt *et al.* 2001) as professional surfers. This provided a suitable reference point to identify the unique anthropometric profile of surfers in this specific category. The sample used in the current study gave representation over a much wider range of abilities by investigating the anthropometric profiles of surfers who ranged level 3 surfers who are able to ride laterally along the wave face and generate speed by pumping, to those of level 8 professional surfers. When analysing the results relating to the professional and intermediate male surfer groups there were non-significant relationships between all of the anthropometric variables and the rank of the surfers in that group, suggesting that all of the participants in those groups had made similar anthropometric adaptations as a result of their surfing practice (Ericsson and Charness 1994). In analysing the intermediate male surfers significant negative relationships were found with the measures of adiposity (endomorphy and body fat percentage) and performance. This can be interpreted in two ways; firstly, maintaining a relatively low level of adiposity is facilitative in improving surfing performance (and) or secondly, through engaging in surfing activity to the extent which allows progression from HSSR level 3 to HSSR level 6 low adiposity is encouraged. The former statement suggests that coaches and surfers of intermediate ability should seek to maintain moderate levels of adiposity in their attempts to improve performance through offering insulation from the cold water environment or by offering a source of energy during extended surfing sessions (Lowdon 1980, Felder *et al.* 1998, Ranallo and Rhodes 1998) . The latter statement suggests that moderate participation in surfing could be a useful strategy for weight management in 18-25 year olds. When the data for the three groups of male surfers were combined it was found that increased muscularity and decreased adiposity were associated with overall ranking. Emergent research from Fernandes-Lopez *et al.* (2012) who investigated relationships between professional junior surfers from the Basque region of Spain support the findings presented here in that the participants of that study were of a similar age to those in the present study but would be rated higher (level 8) on the HSSR. The participants of the Fernandes-Lopez *et al.* (2012) study displayed similar values for ectomorphy and endomorphy but (slightly) increased values of mesomorphy in line with the relationships between ability and mesomorphy found in this study. Fernandes-Lopez *et al.* (2012) found a significant relationship between rank of the surfers in their study and the endomorphy score of the surfers suggesting that it might be beneficial for surfers in this population to maintain moderate levels of body fat. A similar relationship was found in this study however statistical analysis found this to be insignificant (P = 0.07). Further studies should consider the impact of this relationship in junior surfers.

The data presented in this thesis evaluating the anthropometric variables of surfers of varied ability represents the first study of this kind. The literature does not indicate any other study that has measured the relationships of anthropometric variables with performance in surfing across intermediate, advanced and elite surfers. As such this chapter makes a contribution to knowledge in this cognate area. Future research directions should focus on the relative paucity of information in the literature relating to the anthropometric profiles of high performance female surfers and whether the changes in the judging criteria has caused any changes in the profile of female surfers. There exists some opportunity to investigate why increased body fat percentage appears to be related to performance in elite level junior surfers as this finding seems to be in contrast with the results for other ability groups of surfers. Participation in surfing at an intermediate level is related to a moderate levels of adiposity, increased levels of fitness, and a considerable energy demand. Thus surfing, in a controlled environment, could be considered as an intervention for overweight adolescents who are disengaged with other mainstream forms of sport and exercise; therefore future research could investigate the efficacy of such an exercise programme.

Chapter 3 investigated physiological parameters and their relationship to ranking in male high performance junior surfers. At the time of the investigation there was no other study that had investigated the physiological parameters of high performance junior surfers. The study found that the junior surfers were above average In comparison to other non-surfing European adolescents for grip strength and that the power output associated with $\dot{V}O_{2\,Peak}$ was significantly correlated to national ranking in this sample. Emergent research from Fernandes-Lopez *et al.* (2012) measured $\dot{V}O_{2\,Peak}$ and the associated power output did not report these values or any relationships with ranking. Fernandes-Lopez *et al.* (2012) did find a significant relationship with the power output at the lactate threshold and at OBLA with group ranking. The significance of lactate threholds with national ranking suggest that the exercise intensities associated with these indices hold indices importance during surfing. The findings reported in Chapters 2 and 3 should be considered together in that they provide a basis for a test battery that could be used in the indentification of talent through the measurement of parameters that are related to rank in junior high performance surfers such as the power output at $\dot{V}O_{2\,Peak}$. The chapters also provide normative data with which to compare the anthropometric measures of other high performance junior surfers.

Blood lactate parameters have repeatedly been found to be related to ratings of ability in surfers (Mendez-Villanueva *et al.* 2005, Farley *et al.* 2011, Fernandes-Lopez *et al.* 2012). However blood lactate sampling is not always possible with juvenile participants due to compliance issues associated with young individuals and as such future research should investigate the use of non-invasive assessment of the lactate threshold using the ventilatory threshold (T_{vent}) (Jones and Doust 2001). T_{vent} can be assessed by using breath-by-breath analysis during incremental exercise testing and is identified by a disproportionate increase in $\dot{V}CO_2$ (Beaver *et al.* 1986), and the increase in ventilatory equivalent for O_2 ($\dot{V}_E$ / $\dot{V}O_2$) without a concomitant increase in CO_2 ($\dot{V}_E$ / $\dot{V}CO_2$) (Caozzo *et al.* 1982).

Chapter 4.0 evaluated the effect of five days of supplementation with 20g a day of creatine monohydrate on a sample of intermediate ability surfers. Due to the intermittent high intensity nature of surfing (Meir *et al.* 1991, Mendez-Villanueva *et al.* 2006, Farley *et al.* 2012) and the reported ergogenic effects of creatine supplementation on sprint activity (Williams *et al.* 1999) it was hypothesised that creatine supplementation would improve surfing performance. A significant effect of creatine supplementation was found on the body mass and the total body water of the participants which indicates that the creatine loading strategy was successful. The increases in these markers associated with increased muscle creatine were also accompanied by increases in peak power output in the laboratory test of repeated upper body anaerobic power which further supports the notion that the creatine loading was successful. However when surfing performance was analysed no significant effects were found. The inability to detect an ergogenic effect might be explained as a matter of the metabolic processes (the immediate energy system) enhanced by creatine supplementation being of little importance during surfing. Given the descriptions of surfing as comprising of high intensity bouts interspersed by periods of rest and aerobic exercise (Meir *et al.* 1991, Mendez-Villanueva *et al.* 2006, Farley *et al.* 2011) this explanation appears to be unlikely. Surfing performance has been found to be highly variable (Mendez-Villanueva *et al.* 2010) and as such it might prove difficult to measure any improvement in performance as a result of supplementation over a discrete period of time with the effects of wave size, tide, wave period and wind direction all potentially having an effect on performance. The current study attempted to match the conditions between the pre- and post-supplementation measures of performance but although conditions were similar it is very unlikely to reproduce conditions exactly in a real world setting.

When assessing the ergogenic effects of any intervention such as creatine supplementation on surfing it is possible to control laboratory testing to an extent that effects might be measured. However the issue lies in measuring on-water effects due to changes in conditions. This could be overcome by using high performance surfers who would be associated with less variable performances and test these surfers in an environment that offers a realistic but controlled representation of surfing. Emergent technologies are now creating wave pools that can offer a "ride-able" wave currently there exists the Wadi adventure wave pool in the United Arab Emirates (http://www.wadiadventure.ae/) and the Wave Garden (http://www.wavegarden.com/) in France which provide a realistic surfing wave. There is planning for a wave pool in Bristol and North Wales in the UK (http://www.the-wave.co.uk) based on the technology of the Wave garden, and the Kelly Slater Wave Company (http://www.kswaveco.com) is looking to develop a circular continuous wave pool.

These pools might provide the opportunity to test the demands of wave riding in a repeatable manner. Future studies should evaluate the comparison in the physiological demands of "wave pool surfing" in comparison to traditional surfing before attempting to utilise these facilities to test the ergogenicity of supplements in surfing or for the assessment of any intervention intended to improve surfing performance. Research has found that creatine supplementation in combination with sodium bicarbonate is beneficial in repeated sprint and intermittent exercise (Mero *et al.* 2004, Barber *et al.* 2013); and that dietary Nitrite supplementation improves intermittent exercise. Future studies should consider the ergogenic effect of these supplements in surfers. The study outlined in chapter 4 did not confirm that the supplementation protocol had been successful in achieving an increase in muscle PCr stores, instead this was implied by measurement of the associated increase in TBW (Kutz and Gunter 2003) if possible any future research studies of this type would utilise muscle biopsy to identify whether the creatine loading had been successful and that any resultant increase in muscle PCr had “washed-out” before performing a cross over (Williams *et al.* 1999). The participants of the creatine supplementation study were identified as intermediate surfers and as such not all participants were familiar with the demands of competitive surfing. Due to the spread of ability in this group it is unlikely that creatine supplementation would have had any effect on the outcome of the competition as the surfers with the highest levels of skill were consistently outperforming the less able surfers regardless of supplementation status. Future studies of this type would incorporate high performance surfers of approximately equal ability, thus their performances would exhibit less natural variation across competitions (Mendez-Villanueva *et al.* 2010) and the effects of supplementation on comparative performance might be more apparent.

Chapter 5 investigated the effects of wave size and period on the physiological demand and performance indices of surfing. This study found that there were relationships between the wave size, wave period and ability levels of the surfers with the physiological and performance parameters of surfing. In this respect this study provides novel and original results that contribute to the body of knowledge as some authors (Meir *et al.* 1991, Mendez-Villanueva and Bishop 2005, Farley *et al.* 2012) have suggested the environmental factors and wave conditions might affect performance and physiological response but no other study has actually investigated these relationships. When comparing between the physiological profiles and performance parameters of surfing in the existing literature the results of the current study provide greater insight as to why differences might occur. When authors are reporting the physiological and or performance profiles of surfing they should also provide information relating to the surf conditions in which the study took place to allow meaningful comparisons between sessions and studies. The analysis of performance and physiological response of specific surf locations in given conditions would allow surfers and coaches to tailor training for a particular event. Moreover understanding the metabolic demand of a surfing location will allow surfers to properly prepare in terms of nutrition to ensure that energy balance is achieved to optimise performance and weight management. Considering the results reported in Chapters 2, 3 and 5 we can see that surfing encourages a relatively lean body composition, high levels of upper body aerobic fitness and a mean energy expenditure of 493 $kcal.hr^{-1}$ during surfing which is comparable the values found in previous research (Meir *et al.* 1991). For these reasons surfing could be considered as an alternative form of exercise for the obese, or overweight or for individuals who are disengaged with physical activity. The study investigating the effect of wave size and period on the physiological demand and performance indices of surfing provided novel information but further studies can be performed to draw out and minimise weaknesses in the methodology. There was variation in duration of the surfing sessions as these were determined by the participant or the time available to surf and although the data were standardised into hourly values there exists the assumption that the participants behaved in a “normal” manner across all sessions regardless of the duration of the surfing session.

The participants utilised in this study varied in their levels of surfing ability and there were significant negative correlations found between HSSR and the average heart rate during surfing as a percentage of the maximum found in the laboratory, the percentage of time in the “intermittent” zone, total energy expenditure and positive correlations with the percentage of time spent in the “steady” zone, maximum ride speed, percentage of distance riding, percentage of time riding, total distance covered and the average speed during the surf session. These relationships were controlled for in the subsequent analyses by using partial correlations controlling for surfer ability but this result is important as it tells us that the physiological demands and performance parameters for any given session will vary by the nature of the ability of the surfers; currently no other study has investigated this relationship. If surf sessions or locations of sessions are to be compared they should be done so considering the ability level of the participants or by matching the ability of the participants at each location. This is the first study to utilise GPS data in a manner that provides data relating to individual rides and the activity break down of surfing in varying wave conditions. This study provides a wholly objective method of comparison of sessions by using mathematical parameters for the determination of surfing rides. Enhancement of the external validity in future studies relating to the changes in surfing performance as a result of ability, location or conditions could be achieved by combining the GPS method to generate ride characteristics with notational / video analysis to provide information regarding the contribution of different activities such as paddling, riding, waiting and duck diving etc.

6.1 Limitations

During data collection for the study described in Chapter 5 difficulties were encountered with the GPS and heart monitors as the systems were not robust enough to deal with the surf environment. Initially Polar RS800CX watches were used in combination with Wearlink W.I.N.D ™ chest straps and G3 GPS units. Although the watches and GPS units were rated as waterproof to 5m many units suffered failure due water ingress in 2m surf, additionally the Wearlink W.I.N.D ™ was unable to transmit heart rate data through water when the surfers submerged their chests. These factors led to a number of failed data collection sessions and it was decided that this equipment was to be replaced by Polar RCX5 monitors with T31 chest straps and G5 devices. Unfortunately valuable time and data collection opportunities were lost during the process of acquiring funding and purchasing the new equipment. The G5 GPS units were rated as IPX7 and as such should be able to resist water ingress when submersed to 1m, however both GPS units and the watches were placed in a protective dry bag and placed down the back of the surfer's wetsuit as modern wetsuits are essentially "dry". Using this strategy overcame the limitations due to the marine environment however the system still suffered from loss of GPS signal due to geographical features such as cliffs. Authors embarking in similar studies should consider the feasibility of the use of such equipment in the surf environment to ensure minimal equipment failure and data loss.

6.2 Future research directions

This section outlines future studies that extend the thematic programme of research presented within this thesis:

1) *Anthropometric variables and their relationship to performance in elite female surfers.*

Lowdon (1980) provided the only summary of the somatotype of international female surfers. Since the time of that study the governing body for professional surfing; the Association of Surfing Professionals (ASP) has modified its regulations so that female surfers no longer have their own judging criteria and are judged by the same criteria as the male contestants specifically removing the requirement for "Grace" and replacing this with an emphasis on "speed, power and flow". It is hypothesised that this will have driven a change in the anthropometric profiles of female surfers towards one which is representative of more powerful characteristics. This is supported by the preliminary findings of the current study that found that mesomorphy was associated with ability in female surfers.

2) *Evaluation of the anaerobic threshold as a non-invasive method of predicting rank in high performance junior surfers using isokinetic ergometry.*

The research presented in this thesis is unique in that it reports a significant relationship between the power output associated $\dot{V}O_{2\ peak}$, and the ranking of high performance junior surfers. There is a growing body of literature that suggests parameters associated with the lactate threshold can predict ability / rank in surfers (Mendez-Villanueva *et al.* 2005, Loveless and Minahan 2010, Fernandes-Lopez *et al.* 2012) however the participant compliancy was found to be low for these measurements in the data collection process of this thesis. Beaver *et al.* (1986) suggest that the lactate threshold can be measured non-invasively using the anaerobic threshold during a modified incremental exercise test. The investigations of aerobic fitness in this thesis and other such studies in the literature (Mendez-Villanueva *et al.* 2005, Loveless and Minahan 2010, Loveless and Minahan 2010, Farley *et al.* 2011, Farley *et al.* 2012, Fernandes-Lopez *et al.* 2012) have all used forms of wind braked paddling ergometers. However the power output during these tests is generally self-selected by the participants and subjectively monitored by the experimenters leading to the possibility of variation in power output associated with any given increment. The implementation of upper body isokinetic dynamometry in the testing protocol should elicit more robust measurement of peak aerobic power and submaximal parameters with greater validity and reliability (Earnest *et al.* 2005).

3) The effects of creatine supplementation on muscle PCr, repeated upper body power and simulated competition surfing performance in high performance surfers.

The two group research design used in this thesis found five days of 20 g.d^{-1} creatine monohydrate supplementation did not increase body mass, TBW and peak power during a repeated upper body anaerobic power test. The participants in this study will be high performance or professional surfers. This study will utilise the same loading regimen but will incorporate a habituation to the RUBAP test and muscle biopsy measurements pre- and post- supplementation to directly measure muscle PCr cocentration. The study will use a two group double-blind crossover methodology with an extended time for washout to occur following the initial loading regimen (>30 days) (Rawson *et al.* 2004). Surfing performance will be measured in during 25 minute competitive heats in a surfing wave pool with consistent wave size and frequencies used throughout the study. Performance will be assessed through the application of the ASP judging criteria, GPS and video analysis of the competitive heats.

4) *The effects of wave size and period on the physiological demands and performance parameters of high performance surfers in competitive surfing.*

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The data presented in this thesis reports the effects of wave size and period on physiological response and performance parameters across a range of abilities in a recreational setting. This study will primarily be concerned with furthering the research presented here by using a sample of high performance surfers in a competitive setting. This will allow a comparison between competitive and non-competitive surfing and facilitate an investigation into the demands of the competitive element of surfing. Physiological demands will be assessed using the same method as described in this thesis with performance being analysed through the use of the ASP judging criteria, GPS and video analysis.

5) *Comparison of the physiological demands and performance parameters of different types of surf break in varying wind and tide conditions.*

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Appendix 1.0 Application for ethical approval – Anthropometric characteristics of surfers

Faculty of Science

Portland Square A106, Plymouth

To:	Matthew Barlow	From:	Christine Brown
cc.			Secretary to Human Ethics Committee
Your Ref:		Our Ref:	sci:\d:\human ethics:
Date:	2 August 2006	Phone Ext:	2762

Application for Ethical Approval

Thank you for submitting the ethical approval form and details concerning your project:

'Anthropometric characteristics of elite surfers'

I am pleased to inform you that this has been approved subject to the following conditions:

- That participation is restricted to over 18's only
- That an information sheet and consent form are provided for participants detailing the procedures, tests and measurements to be carried out, whether these are invasive or involve any risk or discomfort and the length of time involved
- That a private area is used to conduct the tests and a same sex chaperone is present

I would be grateful if you could send me copies of your amended application, information sheet and consent form for my records. **Please note that approval is not granted until these have been received.**

Kind regards

Christine Brown

Christine Brown

Appendix 1.1 Application for ethical approval – British Surfing Association junior team assessments

Faculty of Science

Portland Square A106, Plymouth

To:	Matthew Barlow	From:	Christine Brown
cc:			Secretary to Human Ethics Committee
Your Ref:		Our Ref:	sci:\d:\human ethics:
Date:	9 October 2006	Phone Ext:	2762

Application for Ethical Approval

Thank you for submitting the ethical approval form and details concerning your project:

'British Surfing Association junior team fitness assessments'

I am pleased to inform you that this has been approved.

Kind regards

Christine Brown

Christine Brown

Appendix 1.2 Participant information sheet British Surfing Association Junior team fitness assessments

Participant information sheet

British Surfing Association Junior team fitness assessments

Dear surfers and parents / guardians,

As part of the training camp the BSA have requested that the University of Plymouth provide scientific support to the team; this will comprise of a battery of physiological tests which will allow coaches to produce effective training regimes to improve your performance.

Sports science support is common in various sports, with athletes benefiting from training regimes based upon the latest scientific research of exercise physiology and sports performance.

The tests will take place during the training camp. The following will outline the tests which are being performed and the rationale behind each test, this first round of tests will serve two main purposes, the first is to help set individual training regimes for each surfer; Secondly, the tests will act as a benchmark to track how well each surfer is doing with their training.

It is important that the surfers know that they do not have to take part in these tests and if they start a test they are free to withdraw at any time. Some of the information generated as a result of these tests may be used by the University of Plymouth for research purposes, however all information held by the University will be treated as confidential and anonymous. If you do not wish for your information to be used by the University of Plymouth for research purposes then you can request that your information be withdrawn.

Please read all of the information contained within this information sheet, and if you are happy to be involved with these tests then the informed consent form needs to be signed by your parent or guardian and by yourself. If you are over 18 then the form does not need to be signed by a parent or guardian as you can sign this yourself.

If you have any questions about these tests then please do not hesitate to contact the principal investigator:

Matthew Barlow

tel: 01752 232 469

Email matthew.barlow@plymouth.ac.uk

The Fitness Assessments

Before any of the tests are performed a medical questionnaire will be completed to identify any reasons why you may not take part. Your resting heart rate and blood pressure will also be measured to ensure your health.

Ergometer test

This test requires you to paddle on a specially designed machine (similar to a rowing machine), whilst you are paddling you will be wearing a heart rate monitor and breathing through a special mask which measures the amount of air you breathe and the composition of that air. The test will comprise of two parts. Part 1 of the test will require you complete 5-7 three minute stages, each stage progressing form easy to moderate exercise intensities, at the end of each stage a small finger prick sample of blood will be taken. When you have reached a certain point called the lactate or anaerobic threshold you will be given a short rest before starting the second part of the test. Part 2 of the test will require to paddle on the machine continuously with the paddle rate increasing every minute. The test will progress in this manner until you reach a heart rate which is 85% of your maximum. The 85% maximum is calculated by using the following equation:

[(220 – age in years) ÷ 100] * 85

Part one of the test allows the measurement of your blood lactate threshold or your anaerobic threshold, this is very important in assessing your level of fitness and setting appropriate training intensities. Part 2 of the test will identify your $\dot{V}O_{2max}$ which is essentially the maximum exercise intensity at which you can perform.

Flexibility test

The flexibility test is called a sit and reach test, it is a relatively simple test whereby you are sat down and we measure how far you can reach towards you toes. This gives a good estimation of overall flexibility.

Strength and power tests

Strength and power will be measured by firstly how far you can throw a 2Kg medicine ball from a seated position. The second test will be a jump test whereby we will measure how high or how far you can jump.

Balance Tests

Your balance will be assessed in two ways, firstly you will perform a blind standing stork test. The stork test requires you to stand on one leg with the toes of the other leg on your knee, you place your hands on your hips and when ready close your eyes and raise up onto your toes; we then time how long you can maintain this position.

The second test will be a balance board test where we time how long you can balance on a special balance board.

Agility test

To test your agility and dynamic balance you will perform the pop up test. This test requires you to perform as many pop ups as possible in 30 seconds.

Body composition assessment

This will involve full body composition assessment which will include the measurements of height, body mass, skinfold thicknesses, girths and breadths. These will allow indices such as body fat and muscle mass to be assessed. This including an explanation of the measurements will take approximately 30 minutes. Due to the nature of the measurements a small but relatively private area is required, however all participants must be accompanied by a chaperone of the same sex so please bring along a friend. The procedures are explained in greater detail later.

This assessment will involve measurements of height and weight, skinfold measurements, girths of the biceps, calf waist and hips and breadths of the humerous and femur bones. In order for these measurements to be taken, minimal clothing is required. Each measurement and the site at which they are measured are explained below. Measurements sites require the measurer to locate anatomical landmarks by palpation (touch) these are explained.

Before, the measurements can be taken it will be necessary to mark the measurement sites this will be done using a water based gel pen which can be easily removed, if you believe you may be allergic to water based ink then it will not be possible for you to participate. The sites that will be marked are as follows:

Bicep and tricep sites – exactly half way between your elbow (radiale) and collar bone (acromiale) in line with the middle of each muscle. The measurer will palpate for the end of your collar bone and the end of your forearm.

Subscapular – diagonally 2cm below your shoulder blade. The measurer will palpate for the location of the point of your shoulder blade.

Illiac crest – directly above your hip bone, to mark this, the measurer will need to place their hands on your hips and locate the top of your hip bone.

Supraspinale – before this measurement can be taken, it will be necessary for the measurer to find a anatomical landmark called the iliospinale, To find this the measurer will need to palpate for a notch in the front of your hip bone, you may know where this is and the measurer will ask you to point it out. The site is marked by drawing an imaginary line from your armpit to this notch and crossing this with a line from the iliac crest.

Abdominal – 5 cm to the right if the midpoint of your navel.

Front thigh skinfold – this is taken half way along your thigh ion the midline, to mark this the measurer will need to palpate for the top of your knee cap, they will also ask you to identify the fold made between your thigh and trunk..

Medial Calf – This is measured at the widest point of your calf on the medial (inside) aspect.

All skinfold measurements are measured using skinfold callipers, please ask the measurer to show these to you if are unsure what they are.

Muscle girths – the measurer will assess the size of your muscles by measuring the circumference of you biceps (tensed and relaxed) and your calf (relaxed).

The assessment will also involve measuring the circumference around your waist (at the narrowest point) and the circumference around your hips (at the widest point).

The breadth of your humerous bone and femur will be measured using special (condyle) callipers.

Height and weight are simple measurements which will be measured using a stadiometer and weighing scale.

These measurements will allow us to track muscular development and monitor nutritional status.

Please complete the following informed consent form for each aspect of the testing. You are free to withdraw from any aspect of the testing at any time.

UNIVERSITY OF PLYMOUTH

FACULTY OF SCIENCE

Human Ethics Committee

CONSENT TO PARICIPATE IN RESEARCH PROJECT / PRACTICAL STUDY

Name of Research Director / Practical Supervisor/ Undergraduate Project Advisor

Matthew Barlow

Title of Research Project / Practical Exercise / Field Study

British Surfing Association junior team fitness assessments

Level of Work

PhD project

Brief statement of purpose of work

To assess the fitness status of junior surfers

<u>PLEASE TICK AS APPROPRIATE, AND SIGN & DATE THE FORM</u>

The objectives of this research/exercise/programme of work have been explained to me □

I understand that I am free to withdraw from the research project/practical exercise at □

any stage

I understand that the Supervisor of this work will have undertaken, as far

as possible, to avoid any risks, and that safety and health risks will have been

separately assessed by appropriate authorities (e.g. under COSSH regulations)

□

Under these circumstances, I agree to participate in the research project.

Name: ……………………………………….

Signature: ....…………….. Date: ....…………..

Under these circumstances, I agree that the person named above may participate in the outlined research project.

Name (parent/guardian): ……………………………………….

Date: ....…………..

Please sign for each of the aspects of testing to which consent is given.

Ergometer test

Signature (parent/guardian):.. Date: ....

Flexibility

Signature (parent/guardian):.. Date: ....

Strength and power tests

Signature (parent/guardian):.. Date: ....

Balance tests

Signature (parent/guardian):.. Date: ....

Agility tests

Signature (parent/guardian):.. Date: ....

Body Composition

Signature (parent/guardian):.. Date: ....

Appendix 1.3 Participant information sheet Anthropometric characteristics of elite surfers

Background: There have been many studies in which the anthropometric characteristics of various athletes have been evaluated, with inferences drawn between common body types and composition with performance within a specific sport (Landers et al. 2000; Reilly et al. 2000; Bourgois et al. 2001; Watts et al. 2003). This has also been performed within surfing but using much smaller samples (Lowden 1983; Felder et al. 1998) with a combined sample of 112 for both studies; suggesting that surfers are shorter and lighter than age matched sporting populations (Lowden 1983). These results were based on a sample of 76 surfers all of which were Australian. This was a relatively small and specific sample and it would be naïve to assume that these values would be representative of the world population of surfers. Furthermore, due to advances in judging criteria and surfboard design it is likely that there has been a change in the somatotype of successful professional surfers during recent years and to date there is no existing literature which describes the physiques of British surfers.

Aims: To measure the Anthropometric characteristics of a broad sample of elite surfers and determine whether there is a certain body type which is common to individuals participating in high level competition. Furthermore the study aims to investigate whether there is a relationship between anthropometric characteristics and performance in competition. This will help to develop future training, coaching and nutritional strategies.

Methodology: You (The participant) will undergo a full body composition assessment which will include the measurements of height, body mass, skinfold thicknesses, girths and breadths. These will allow indices such as body fat and muscle mass to be assessed. This including an explanation of the measurements will take approximately 30 minutes. Due to the nature of the measurements a small but relatively private area is required, however all participants must be accompanied by a chaperone of the same sex so please bring along a friend. The procedures are explained in greater detail later.

Outcomes: The results will be treated as confidential and collated by the principal investigator to be analysed with respect to the aims of the study. However, all individuals participating in the study will receive a full written report, explaining what each of the measurements mean with a comparison to existing normal values and the values obtained in this study. The report will contain information and advice for future training and nutritional strategies. On request and with the consent of all involved participants, reports can be written in a team format for the use of coaches / team managers.

Nature of measurements

The assessment will involve measurements of height and weight, skinfold measurements, girths of the biceps, calf waist and hips and breadths of the humerous and femur bones. In order for these measurements to be taken, minimal clothing is required. Each measurement and the site at which they are measured are explained below. Measurements sites require the measurer to locate anatomical landmarks by palpation (touch) these are explained.

Before, the measurements can be taken it will be necessary to mark the measurement sites this will be done using a water based gel pen which can be easily removed, if you believe you may be allergic to water based ink then it will not be possible for you to participate. The sites that will be marked are as follows:

Bicep and tricep sites – exactly half way between your elbow (radiale) and collar bone (acromiale) in line with the middle of each muscle. The measurer will palpate for the end of your collar bone and the end of your forearm.

Subscapular – diagonally 2cm below your shoulder blade. The measurer will palpate for the location of the point of your shoulder blade.

Illiac crest – directly above your hip bone, to mark this, the measurer will need to place their hands on your hips and locate the top of your hip bone.

Supraspinale – before this measurement can be taken, it will be necessary for the measurer to find a anatomical landmark called the iliospinale, To find this the measurer will need to palpate for a notch in the front of your hip bone, you may know where this is and the measurer will ask you to point it out. The site is marked by drawing an imaginary line from your armpit to this notch and crossing this with a line from the iliac crest.

Abdominal – 5 cm to the right if the midpoint of your navel.

Front thigh skinfold – this is taken half way along your thigh ion the midline, to mark this the measurer will need to palpate for the top of your knee cap, they will also ask you to identify the fold made between your thigh and trunk..

Medial Calf – This is measured at the widest point of your calf on the medial (inside) aspect.

All skinfold measurements are measured using skinfold callipers, please ask the measurer to show these to you if are unsure what they are.

Muscle girths – the measurer will assess the size of your muscles by measuring the circumference of you biceps (tensed and relaxed) and your calf (relaxed).

The assessment will also involve measuring the circumference around your waist (at the narrowest point) and the circumference around your hips (at the widest point).

The breadth of your humerous bone and femur will be measured using special (condyle) callipers.

Height and weight are simple measurements which will be measured using a stadiometer and weighing scale.

If you have any questions please ask the measurer and they will be happy to explain any of the procedures.

.

UNIVERSITY OF PLYMOUTH

FACULTY OF SCIENCE

Human Ethics Committee Sample Consent Form

CONSENT TO PARICIPATE IN RESEARCH PROJECT / PRACTICAL STUDY

Name of Principal Investigator

Matthew Barlow

Title of Research

Anthropometric characteristics of elite surfers

Level of Work

9 Staff research project

9 M.Phil / PhD project

9 Project for taught Masters / Doctoral programme

9 Undergraduate Project

9 Exercise forming element of taught programme

Brief statement of purpose of work

To assess the anthropometric characteristics of elite surfers and investigate whether certain characteristics are related to performance.

PLEASE TICK AS APPROPRIATE, AND SIGN & DATE THE FORM

The objectives of this research have been explained to me.

I understand that I am free to withdraw from the research at any stage, and ask for my data to be destroyed if I wish.

I understand that my anonymity is guaranteed, unless I expressly state otherwise.

I understand that the Principal Investigator of this work will have attempted, as far as possible, to avoid any risks, and that safety and health risks will have been separately assessed by appropriate authorities (e.g. under COSSH regulations)

Under these circumstances, I agree to participate in the research.

Name: ……………………………………….

Signature: ....……………..   Date: ....……………..

Faculty of Science Human Ethics Committee

List of School Representatives

School of Psychology	Professor Michael Hyland
	Prof Tim Perfect
	Dr Joyce Benenson
School of Earth, Ocean and Environmental Sciences	Dr Jo Richards
School of Biological Sciences	Dr David J. Price
Centre for Computational and Theoretical Neuroscience	Professor Chris Harris

Other members of the Committee.

Appendix 1.4 Technical Error of Measurement for Anthropometric measures.

Measure	TEM
Body mass (kg)	0.07
Stature (cm)	0.07
Triceps skinfold (mm)	0.35
Subscapular skinfold (mm)	0.51
Biceps skinfold (mm)	0.25
Iliac Crest skinfold (mm)	0.95
Supraspinale skinfold (mm)	0.35
Abdominal skinfold (mm)	0.52
Front thigh skinfold (mm)	0.39
Medial calf skinfold (mm)	0.55
Relaxed arm girth (cm)	0.28
Flexed arm girth (cm)	0.16
Waist girth (cm)	0.45
Gluteal girth (cm)	0.34
Calf girth (cm)	0.09
Humerus breadth (cm)	0.02
Femur breadth (cm)	0.03

Appendix 2 (Abstract) Anthropometric measures and prediction of competitive national rank in male high performance junior British surfers

Barlow, M.J. *1;* Findlay, M. 1; Gresty, K 1 and Cooke, C.B. 2

1 Department of Science, University of Plymouth, Plymouth, United Kingdom.

2 Carnegie Faculty of sport and education, Leeds Metropolitan University, Leeds, United Kingdom.

Surfing is a high intensity intermittent exercise which in recent years has experienced a rapid increase in participation rates and growing professionalism amongst competitive athletes. Studies in a variety of sports have indicated that, unless one has a distinctive and specific body form suitable to the sport, there is little likelihood of success in top class performance (Lowdon, 1980: Australian Journal of Sports Medicine 12, 34-39). The aim of this study was to investigate the relationship between anthropometric measures and national ranking in male high performance junior British surfers.

Following institutional ethical approval and the completion of parental informed consent (children giving assent) high performance male surfers (N = 16, age = mean 15.61, s = 1.06 years) participated in anthropometric measures of stature, body mass, skinfolds (Tricep, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf), girths (arm flexed and tensed, waist, gluteal and calf) and breadths (humerus and femur). All measures were taken in accordance with the

guidelines of the International Society for the Advancement of Kinanthropometry (ISAK). These were used to calculate body mass index, waist to hip ratio and body fat percentage using the equation of Yuhasz (1975: Physical fitness manual. London: University of Western Ontario). A correlation analysis was performed using SPSS for Windows (V.15) between the measured physiological variables and the numerical national ranking of the subjects.

Significant ($P<0.05$) correlations were found with Illiac Crest skinfold measurement $r=0.52$ ($R^2 = 0.27$) and body fat percentage $r=0.60$ ($R^2=0.36$). Thus the coefficient`s of determination for these measures suggest that the iliac crest skinfold measure can explain 27% of the variance in ranking and body fat percentage explains 36% of the variance within the sample used. No other significant correlations were found.

The results suggest that within this age group body fatness may be conducive to surfing performance. This is supported by Felder *et al* (1998: International Journal of Sport Nutrition, 8(1), 36-48) and Lowdon (1980) who theorised that increased body fat may well protect the surfer from the cold and wet environment in which they perform.

Appendix 2.1 Poster – Anthropometric measures and prediction of competitive national rank in male high performance junior British surfers.

Anthropometric measures and prediction of competitive national rank in male high performance junior British surfers

Barlow, M.J. [1]; **Findlay, M.** [1]; **Gresty, K** [1] **and Cooke, C.B.** [2]

[1] *Faculty of Science, University of Plymouth, Plymouth, United Kingdom.*
[2] *Carnegie Faculty of Sport and Education, Leeds Metropolitan University, Leeds, United Kingdom.*

Introduction

Surfing is a high intensity intermittent exercise which in recent years has experienced a rapid increase in participation rates and growing professionalism amongst competitive athletes. Studies in a variety of sports have indicated that, unless one has a distinctive and specific body form suitable to the sport, there is little likelihood of success in top class performance (Lowdon, 1980). The aim of this study was to investigate the relationship between anthropometric measures and national ranking in male high performance junior British surfers.

Figure 1. Participant competing in the 2008 English National Championship

Method

Following institutional ethical approval and the completion of parental informed consent (children giving assent) high performance male surfers (N = 16, age = mean 15.61, s = 1.06 years) participated in anthropometric measures of stature, body mass, skinfolds (Tricep, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf), girths (arm flexed and tensed, waist, gluteal and calf) and breadths (humerus and femur). All measures were taken in accordance with the guidelines of the International Society for the Advancement of Kinanthropometry (ISAK). These were used to calculate body mass index, waist to hip ratio and body fat percentage using the equation of Yuhasz (1975). A correlation analysis was performed using SPSS for Windows (V.15) between the measured physiological variables and the numerical national ranking of the subjects.

Discussion

Significant ($P<0.05$) correlations were found with Illiac Crest skinfold measurement r=0.52 ($R^2 = 0.27$) and body fat percentage r=0.60 ($R^2=0.36$). Thus the coefficient`s of determination for these measures suggest that the iliac crest skinfold measure can explain 27% of the variance in ranking and body fat percentage explains 36% of the variance within the sample used. No other significant correlations were found. The Somatotype scores, body mass and stature of these Junior surfers are similar to those reported by Lowdon (1980) for adult surfers.

Results

Measure	Mean +/- SD	Correlation with National Rank Score (* = Significant @P<0.05)
Body mass (Kg)	66.44 +/- 6.54	0.32
Stretch stature (cm)	174.73 +/- 5.06	0.28
Triceps sf (mm)	8.30 +/- 2.55	0.46
Subscapular sf (mm)	9.18 +/- 3.16	0.11
Biceps sf (mm)	4.57 +/- 0.61	0.29
Iliac Crest sf (mm)	10.73 +/-3.98	0.52*
Supraspinale sf (mm)	6.51 +/- 2.67	0.46
Abdominal sf (mm)	11.49 +/- 4.72	0.41
Front Thigh sf (mm)	11.53 +/- 2.63	0.37
Medial Calfsf (mm)	8.91 +/- 2.05	0.38
Arm girth relaxed (cm)	28.87 +/- 4.89	0.17
Arm girth flexed and tensed (cm)	31.33 +/- 2.64	-0.27
Waist girth (min.) (cm)	73.14 +/- 41.30	0.07
Gluteal girth (max.) (cm)	82.17 +/- 136.37	-0.27
Calf girth (max.) (cm)	35.46 +/- 1.91	-0.03
Humerus breadth (biepicondylar) (cm)	8.09 +/- 1.19	0.25
Femur breadth (biepicondylar) (cm)	9.64 +/- 0.96	0.15
Endomorphy	2.31+/- 0.75	0.45
Mesomorphy	5.20 +/- 1.69	0.38
Ectomorphy	2.30 +/- 1.94	-0.50
Body Mass Index (BMI)	21.85 +/- 2.35	0.23
Waist/Hip Ratio (WHR)	0.90 +/- 0.11	0.50
Sum of 6 skinfolds (mm)	55.07 +/- 15.33	0.46
body fat %	9.95 +/- 3.05	0.60*
Sum of 8 skinfolds (mm)	70.45 +/- 19.09	0.48

Conclusions

The results suggest that within this age group body fatness may be conducive to surfing performance. This is supported by Felder *et al* (1998: International Journal of Sport Nutrition, 8(1), 36-48) and Lowdon (1980) who theorised that increased body fat may well protect the surfer from the cold and wet environment in which they perform; furthermore measures of mesomorphy, stature and body mass may be important for identifying junior surfers with championship surfing potential in adulthood.

References

Felder *et al* (1998) International Journal of Sport Nutrition, 8(1), 36-48.

Lowdon, B. J. and N. Pateman (1980). "Physiological parameters of international surfers." Australian Journal of Sports Medicine **12**: 30-33.

Mendez-Villanueva, A. and D. Bishop (2005). "Physiological aspects of surfboard riding performance." Sports Medicine **35**(1): 55-70.

Yuhasz (1975) Physical fitness manual. London: University of Western Ontario.

The authors would like to thank the British Surfing Association for their support in this study.

Appendix 3 Abstract – Physiological indices of fitness and prediction of competitive national rank high performance juniors British surfers.

Physiological indices of fitness and prediction of competitive national rank in high performance junior British surfers

Barlow, M.J. [1]**; Findlay, M.** [1]**; Gresty, K** [1] **and Cooke, C.B.** [2]
[1] *Department of Science, University of Plymouth, Plymouth, United Kingdom.*
[2] *Carnegie Faculty of sport and education, Leeds Metropolitan University, Leeds, United Kingdom.*
Correspondence: matthew.barlow@plymouth.ac.uk

Introduction

Surfing is a high intensity intermittent exercise which in recent years has experienced a rapid increase in participation rates and growing professionalism amongst competitive athletes. There has been some research of the physiological aspects of surfing performance and indices of fitness which may be related to competitive performance in adults (Lowden & Pateman, 1980; Mendez-Villanueva & Bishop, 2005) with peak power output and the exercise intensity associated with a blood lactate concentration of 4mmol.L^{-1} being significantly correlated to ranking. However, little information is available regarding junior surfers.

Methods

Following institutional ethical approval and the completion of parental informed consent (children giving assent) 19 elite male (age = (mean ± SD) 15.44 ± 1.40 years, height = 170.55 ± 7.84 cm, body mass = 63.71 ± 6.58kg) surfers participated in assessments of maximal oxygen uptake using a specially adapted ergometer and online gas analysis. Lower body explosive power was assessed using a standing long jump, upper body power was assessed using a medicine ball throw, agility was measured using a "pop-up" test, static balance was measured using a "standing stork test" and dynamic balance was measured using a "wobble board". A correlational analysis was performed between the measured physiological variables and the numerical national ranking of the subjects using SPSS for Windows (V.14).

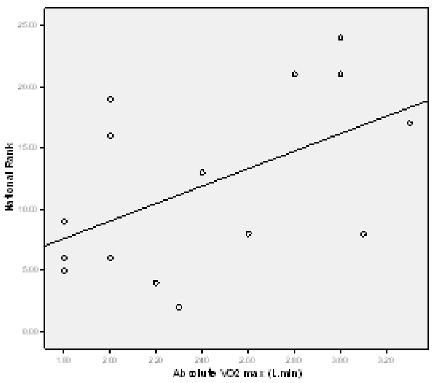

Figure 1 National rank vs. Absolute $\dot{V}_{O_{2max}}$

Results

Statistical analysis revealed that there was a significant Pearson Product moment correlation between Absolute $\dot{V}_{O_{2max}}$ and national ranking ($r=0.519$, $P<0.05$, $R^2=0.269$) and the coefficient of determination suggests that 26.9% of the variation in national ranking is explained by absolute $\dot{V}_{O_{2max}}$. No other variables were significantly correlated to national ranking.

Conclusion

The present study suggests that aerobic fitness is the most important factor for achieving competitive success when considering the physiological profile of elite junior surfers. Further research is required to ascertain at What point of physical maturity and age blood lactate and peak power measures become significant.

References

Lowden, B. J. and N. Pateman (1980). "Physiological parameters of international surfers." australian Journal of Sports Medicine **12**: 30-33.Mendez-Villanueva, A., J. Perez-Landaluce, et al. (2005). "Upper body aerobic fitness comparison between two groups of competitive surfboard riders." J Sci Med Sport **8**(1): 43-51.

Appendix 3.1 Poster –Can physiological indices of fitness predict competitive national rank in high performance junior British surfers.

Can physiological indices of fitness predict competitive national rank in high performance junior British surfers?

Barlow, M.J. [1]**; Findlay, M.** [1]**; Gresty, K** [1] **and Cooke, C.B.** [2]

[1] *Faculty of Science, University of Plymouth, Plymouth, United Kingdom.*

[2] *Carnegie Faculty of Sport and Education, Leeds Metropolitan University, Leeds, United Kingdom.*

Introduction

Surfing is a high intensity intermittent exercise which in recent years has experienced a rapid increase in participation rates and growing professionalism amongst competitive athletes. There has been some research of the physiological aspects of surfing performance and indices of fitness in adults which may be related to competitive performance(Lowden & Pateman, 1980; Mendez-Villanueva & Bishop, 2005) with peak power output and the exercise intensity associated with a blood lactate concentration of 4mmol.L^{-1} being significantly correlated to ranking. However, little information is available regarding junior surfers.

Method

Following institutional ethical approval and the completion of parental informed consent (children giving assent) 19 elite male (mean age = 15.44 ± 1.40 years) surfers participated in assessments of maximal oxygen uptake using a specially adapted ergometer and online gas analysis (see figure 1). Agility was measured using a "pop-up" test, lower body explosive power was assessed using a standing long jump, upper body power was measured using a medicine ball throw, static balance was assessed using a "standing stork test" and dynamic balance was measured using a "wobble board". A correlation analysis was performed between the measured variables and the numerical national ranking of the subjects using SPSS for Windows (V.14).

Figure 1. Participant undergoing assessment of maximal oxygen uptake

Results

Measure	Mean ±SD
Age (years)	15.41 ± 1.28
Stature (cm)	169.01 ± 8.05
Body mass (Kg)	64.07 ± 6.89
Pop ups in 30 seconds	19.33 ± 2.70
Standing long jump (cm)	194.18 ± 55.65
Medicine ball throw (cm)	589.44 ± 81.63
Balance board test (sec)	4.41± 2.04
Standing stork test (sec)	32.55 ± 4.49
VO_2 max (l.min^{-1})	2.92 ± 0.57
VO_2 max (ml.kg^{-1}.min^{-1})	45.20 ± 9.26
Power output @VO_2 max	93.50 ± 16.01

Table 1. Exercise Test Means ± SD

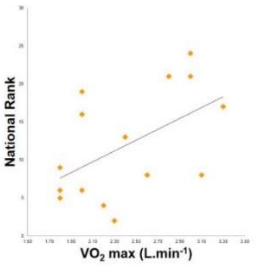

Figure 2. Correlation of National rank versus VO_2 max (l.min^{-1})

Discussion

Statistical analysis revealed that there was a significant relationship between absolute VO_2 max and national ranking ($r=0.519$, $P<0.05$,) see figure 2, with top ranked athletes having lower VO_2 max values. It would appear that VO_2 max is not an appropriate factor to predict rank within a junior group of high performance surfers and no other measured variables were significantly correlated to national ranking in this study. The mean junior VO_2 max (ml.kg^{-1}.min^{-1}) values (see Table 1) were similar to those reported for adult competitive regional level surfers (47.93 ± 6.28) but lower than those of adult European level surfers (mean 50.00 ± 4.67) using a similar assessment methodology (Mendez-Villanueva & Bishop, 2005).

Conclusion

The present study suggests that ranking within a group of high performance junior British surfers cannot be predicted from physiological profile . Further research is required to ascertain at what point of physical maturity and age, blood lactate and peak power measures become significant predictors of performance and whether the measures used can differentiate between novice and high performance junior surfers.

References

Lowdon, B. J. and N. Pateman (1980). "Physiological parameters of international surfers." Australian Journal of Sports Medicine **12**: 30-33.

Mendez-Villanueva, A. and D. Bishop (2005). "Physiological aspects of surfboard riding performance." Sports Medicine **35**(1): 55-70.

The authors would like to thank the British Surfing Association for their support in this study.

Appendix 3.2 Calibration method for Cortex Metalyser 3B.

Calibration Procedures

Before commencing a test it is necessary to complete a calibration of the system to ensure valid results are obtained. The calibration should be repeated every hour.

Select “Calibration” from the menu on the screen.

Select the pressure Icon

In the “Actual Pressure” window, type the current air pressure (mbar) obtained from the barometer located next to the metalyser. Then click start.

The offset will be displayed.

Click transfer to update the pressure calibration in the hardware

Click “ok” then close the Pressure sensor calibration window.

Select the “Gas” Icon.

Once the Gas calibration window is open the settings for gas one and gas two should be displayed, check these values relate to the calibration gases which are to be used.

Click make sure the gas sample line is situated to obtain “fresh air” and is not connected to a mouthpiece or located near to where someone may breathe into the tubes or where exhaust gases or fumes from other equipment may affect the ambient conditions click “start gas 1”. The Metalyser will then sample until it obtains 30 like samples.

Fill douglas bag with required calibration gas. When Metalyser has finished “gas 1” connect the douglas bag to the sample line and click “start gas 2”. The Metalyser will then sample until it obtains 30 like samples.

When complete click “transfer” and then “ok” to transfer the values to the hardware and the “Close”.

Select the “Volume” Icon

When the volume calibration window appears, check that the correct volume is highlighted for the syringe you intend to use.

Attach the Syringe to the mouthpiece and check that the gas sample orifice is plugged.

Click “start”

Complete 5 inhalations and expirations, being sure to make whole strokes of the syringe. The strokes need to be made at the specified flow rate otherwise they will be discounted from the calibration.

When complete click “transfer” and then “ok” to transfer the values to the hardware and the “Close”.

Select the “Print” Icon and print the calibration report, close the print preview window.

Sign the calibration report and file in the Metalyser Calibration File.

Appendix 4.0 Abstract - Oral creatine supplementation has no significant effect on body composition, repeated upper body anaerobic power and competition performance in club level surfers.

Barlow, M.J. 1 ; Findlay, M.F. 1; Gresty, K. and Cooke, C.B. 2

1 Faculty of Science, University of Plymouth, Plymouth, Devon, United Kingdom.

2Carnegie Faculty of Sport and Education, Leeds Metropolitan University, Leeds, United Kingdom.

Surfing is described as an intermittent exercise that comprises bouts of high intensity exercise interspersed with periods of low intensity activity and rest, utilising both the upper body during paddling and the lower body during surfing. The short term supplementation of creatine has been reported to improve maximal power, strength and work performed during repetitive sprint performance (Williams *et al*, 1999: *Creatine the power supplement*, Leeds, Human Kinetics).This study assessed the effect of short term (20g.day^{-1} for 5 days) creatine supplementation on body composition, repeated upper body anaerobic power and competition performance in club level surfers.

Following institutional ethical approval, seventeen club level male surfers (mean: Age 23.06, *s* = 4.21 years, Stature 79.68, *s* = 9.92 cm) underwent a randomised, double blind, placebo controlled, cross-over design study. Testing comprised

assessment of body mass and total body water using bioelectrical impedance analysis, a repeated upper body Wingate (5 x 15 sec) with active recovery (120 sec) and passive recovery (105sec), based on time motion analysis of competitive surfing (Mendez-Villanueva et al, 2003, *Journal of Science and Medicine in Sport*, 23, pp70-74). Competition Performance was assessed by rank in competition and number of waves caught per heat. Participants were tested at baseline and randomly assigned to creatine and placebo groups, receiving 20g.day^{-1} for 5 days of creatine monohydrate (CMH) or placebo (Polyethylene Glycol - PEG). Testing was repeated following supplementation. Participants then underwent a four week wash out period before the groups were reversed and testing repeated.

Table 1. Summary results.

		Creatine (mean ± S)	Placebo (mean ± S)
Body Mass (kg)	**Pre**	72.05±10.50	72.89±10.04
	Post	72.38±10.23	72.68±9.85
Total Body Water (kg)	**Pre**	47.60±5.43	48.66±5.79
	Post	48.19±5.65	48.48 ±5.55
Peak Power (Watts)	**Pre**	664.33±129.13	687.11±150.04
	Post	686.33±143.55	696.01±168.65
Average Power (Watts)	**Pre**	504.63±99.76	509.33±70.70
	Post	515.00±75.02	500.69±108.91
Average wave count per heat.	**Pre**	2.24±2.28	3.00±2.29
	Post	4.3 ±1.89	4.61±1.98

Table 1 shows an insignificant increase in body mass (0.32kg) and total body water (0.59 kg) following 5 days of creatine loading. Oral creatine supplementation also had no significant effect on repeated upper body anaerobic peak power (22.00 Watts increase) and average power (10.37 Watts increase) supporting the findings of Green *et al,* (2001, *Journal of strength and conditioning research,* 15, 36-41) using a similar study design with physically active men. There was no significant effect on competitive performance in terms of ranking or number of waves ridden. These results may be due to the acute effects of the variable surfing conditions during the study period on physiological condition of the participants affecting performance in all tests.

Appendix 4.1 Application for ethical approval – The effect of oral creatine supplementation on surfing performance.

Faculty of Science and Technology

Portland Square A109, Plymouth

To:	Matthew Barlow	From:	Paula Simson
cc:			Secretary to Human Ethics Committee
Your Ref:		Our Ref:	Sci:\x:\human ethics:
Date:	10 January 2009	Phone Ext:	84503

Application for Ethical Approval

Thank you for submitting the ethical approval form and details concerning your project:

'The effect of oral creatine supplementation on surfing performance'

I am pleased to inform you that this has been approved.

Kind regards

Paula Simson

Appendix 5.0 Application for ethical approval – Environmental effects on physiological response and performance in surfing.

Faculty of Science

Portland Square A109, Plymouth

To:	Matthew Barlow	From:	Paula Simson
cc:			Secretary to Human Ethics Committee
Your Ref:		Our Ref:	Sci:\x:\human ethics:
Date:	1 October 2008	Phone Ext:	84503

Application for Ethical Approval

Thank you for submitting the ethical approval form and details concerning your project:

'Environmental effects upon physiological response and performance during surfing'

I am pleased to inform you that this has been approved.

Kind regards

Paula Simson

Barlow, M.J.; Findlay, M.; Gresty, K; and Cooke, C.B Anthropometric variables and their relationship to performance and ability in male surfers. (19th March, 2012) epub ahead of print. **European Journal of Sports Science**. Has been removed due to Copyright restrictions.